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(54) **POLARIZATION RECOVERY IN A DIRECTIONAL DISPLAY DEVICE**

(71) Applicant: **RealD Spark, LLC**, Beverly Hills, CA (US)

(72) Inventors: **Michael G. Robinson**, Boulder, CO (US); **Gary D. Sharp**, Boulder, CO (US); **Graham J. Woodgate**, Henley-on-Thames (GB); **Jonathan Harrold**, Leamington Spa (GB); **Miller H. Schuck**, Erie, CO (US)

(73) Assignee: **RealD Spark, LLC**, Beverly Hills, CA (US)

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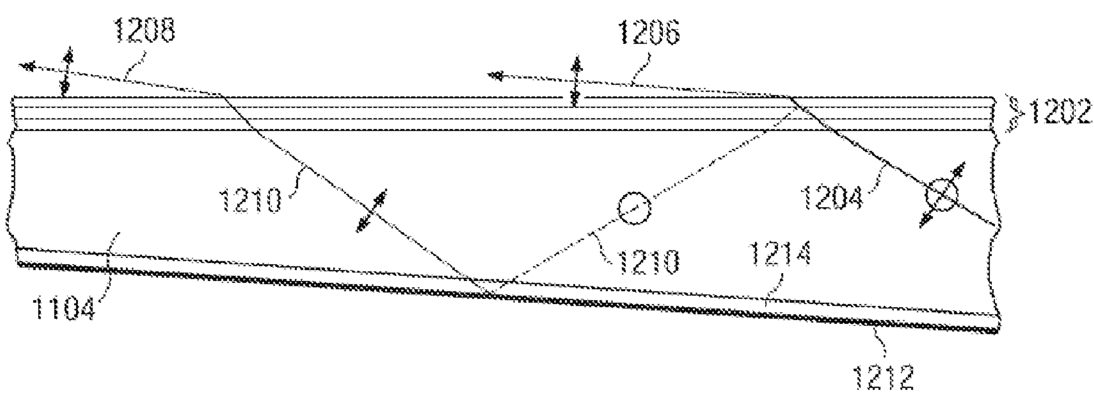
Primary Examiner — Jade R Chwasz
(74) *Attorney, Agent, or Firm* — Penny L. Lowry; Neil G. Mothew

(57) **ABSTRACT**

Disclosed is an imaging directional backlight polarization recovery apparatus including an imaging directional backlight with at least a polarization sensitive reflection component with optional polarization transformation and redirection elements. Viewing windows may be formed through imaging individual light sources and hence defines the relative positions of system elements and ray paths. The base imaging directional backlight systems provide substantially unpolarized light primarily for the illumination of liquid crystal displays (LCDs) resulting in at least 50% loss in light output when using a conventional sheet polarizer as input to the display. The invention herein introduces a polarization sensitive reflecting element to separate desired and undesired polarization states for the purposes of transformation and redirection of the reflected light for usable illumination. Polarization transformation and redirection can be provided by additional components such as retarder films and specular mirror surfaces.

21 Claims, 30 Drawing Sheets



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See application file for complete search history.

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PCT/US2014/042721 International search report and written opinion of international searching authority dated Oct. 10, 2014.
PCT/US2014/060312 International search report and written opinion of international searching authority dated Jan. 19, 2015.
PCT/US2014/060368 International search report and written opinion of international searching authority dated Jan. 14, 2015.
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JP 2015-512810 1st Office Action (translated) dated Feb. 7, 2017.
TW-102117413 Taiwan Office Action (translated) dated Jul. 19, 2017.

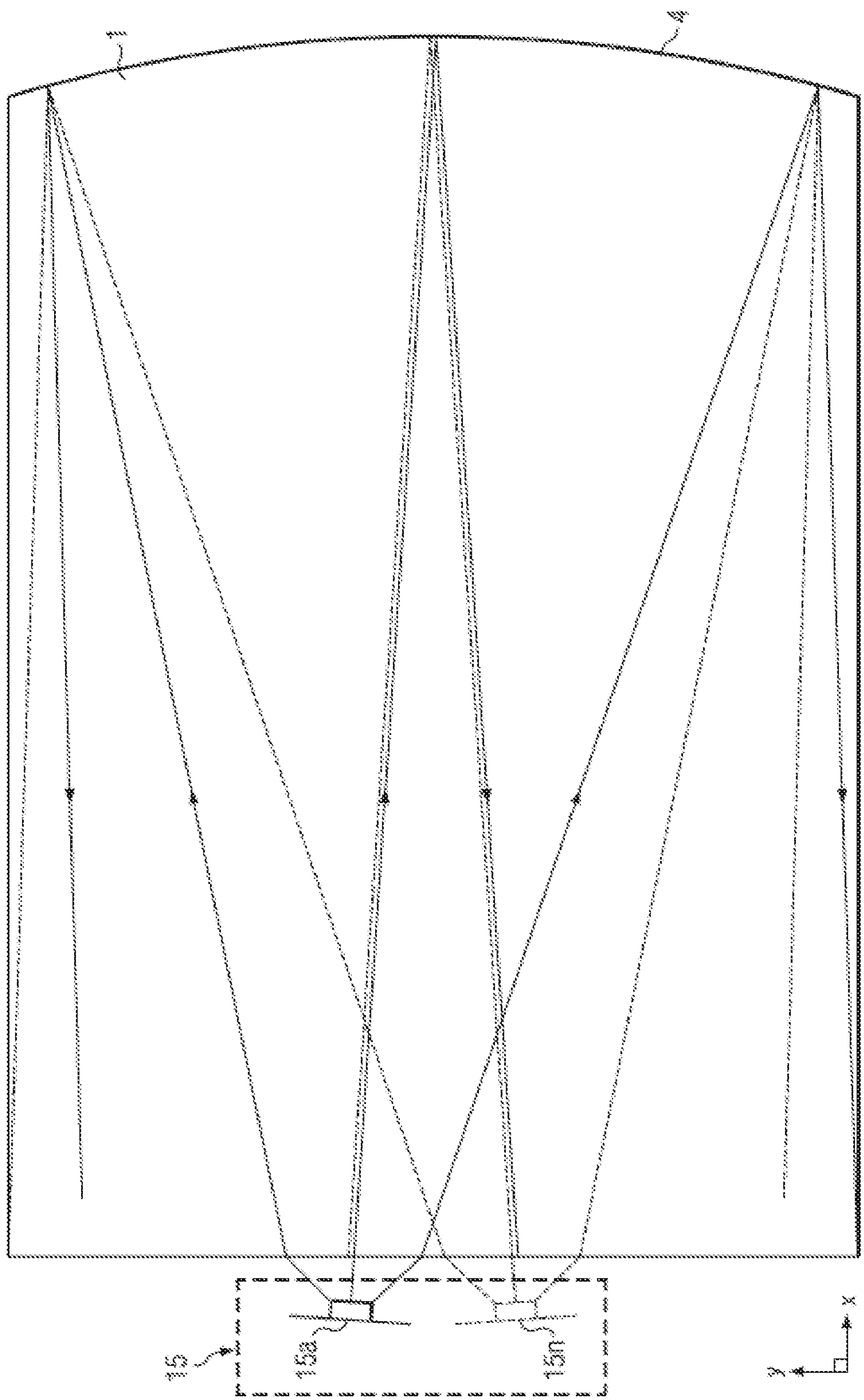

FIG. 1A

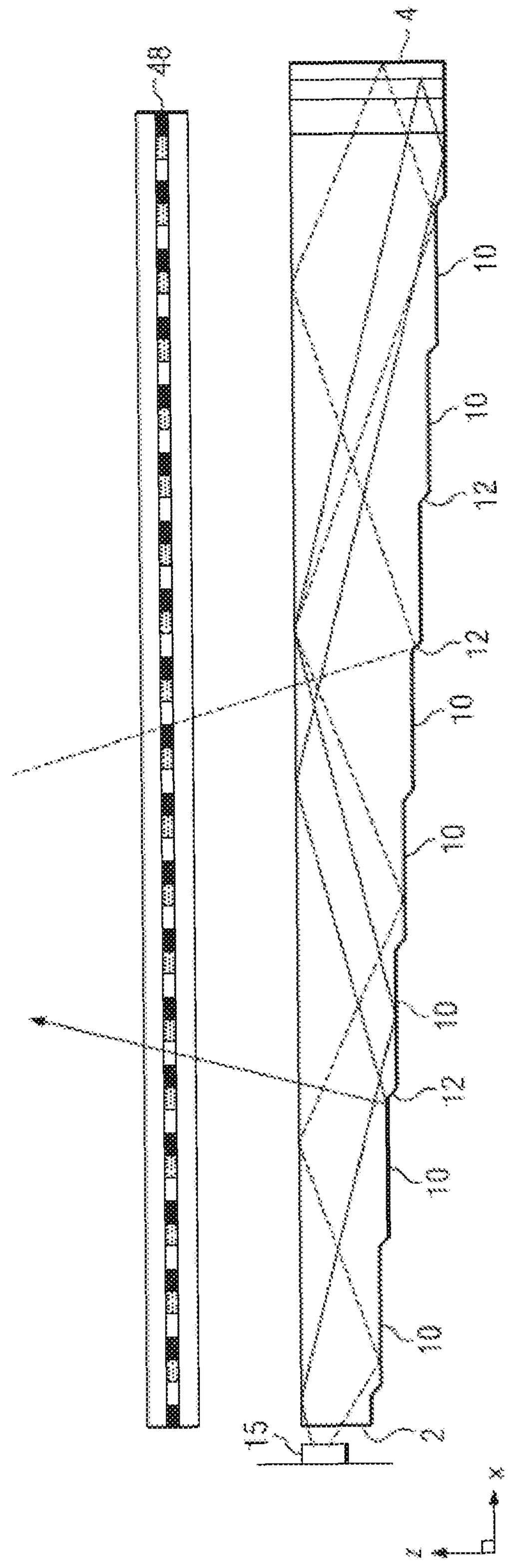

FIG. 1B

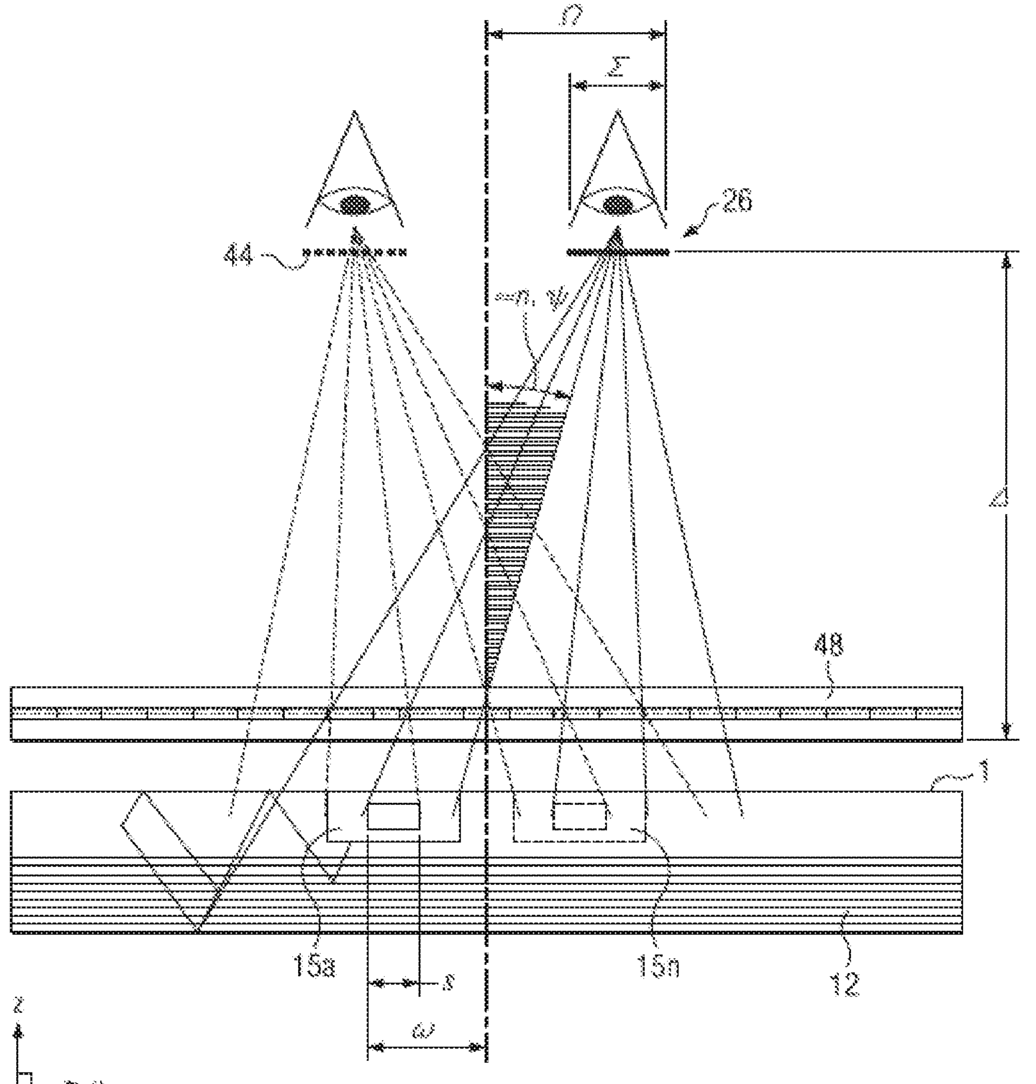

FIG. 2A

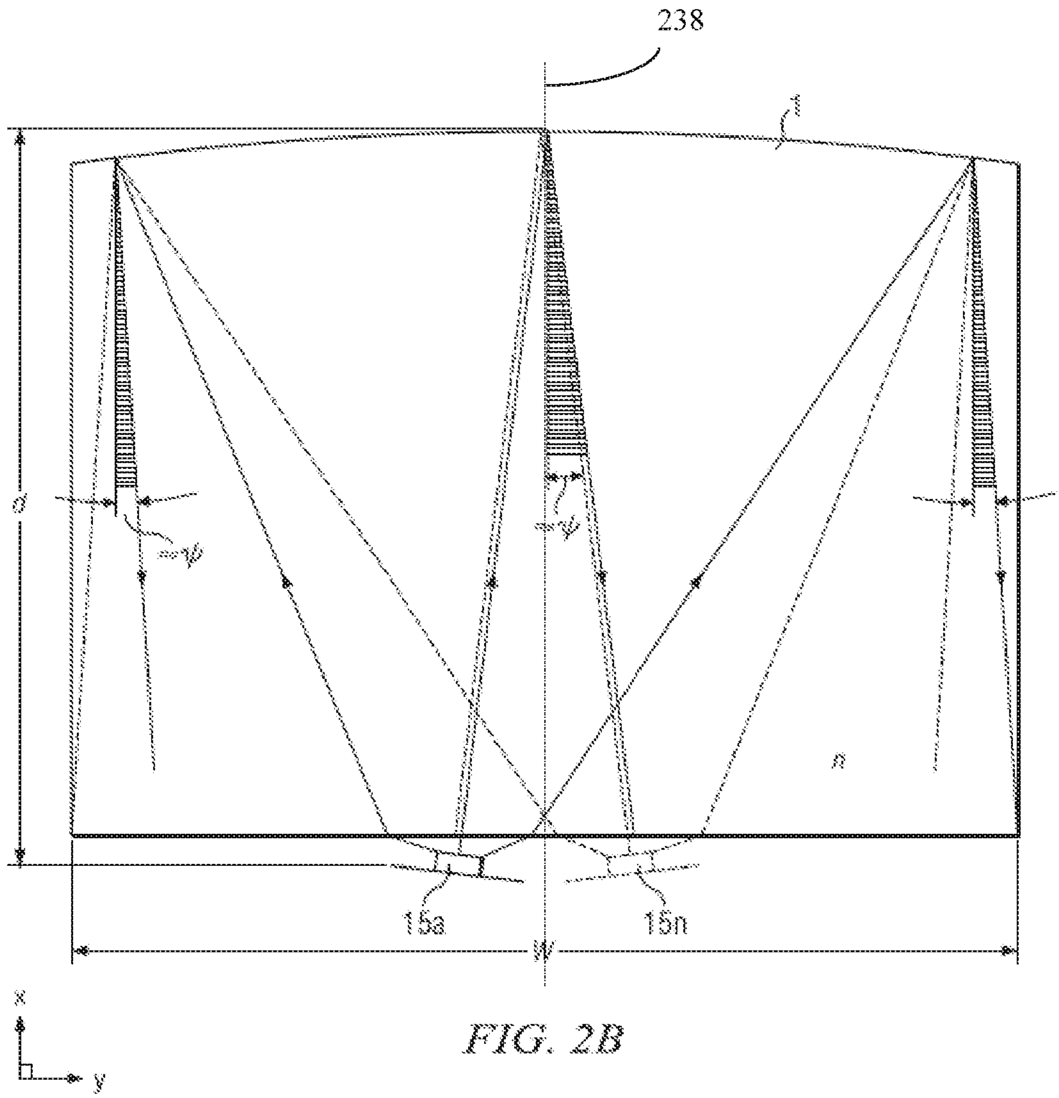

FIG. 2B

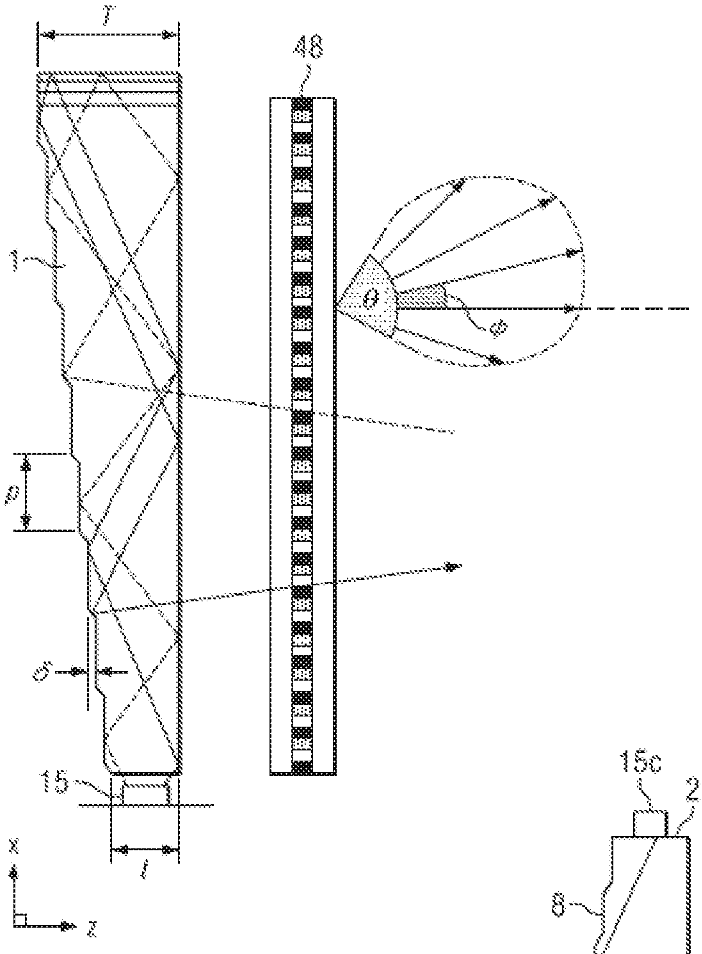

FIG. 2C

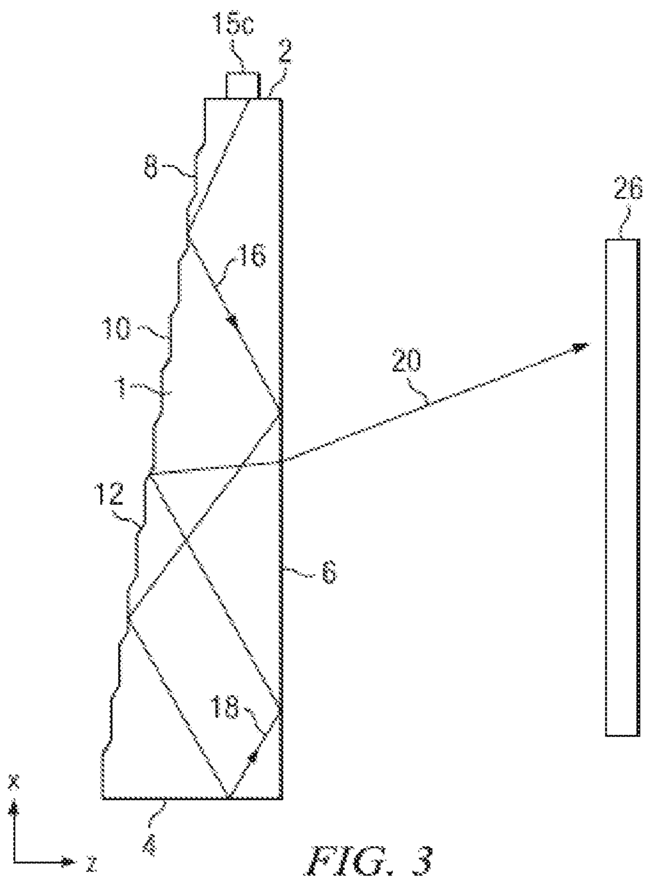

FIG. 3

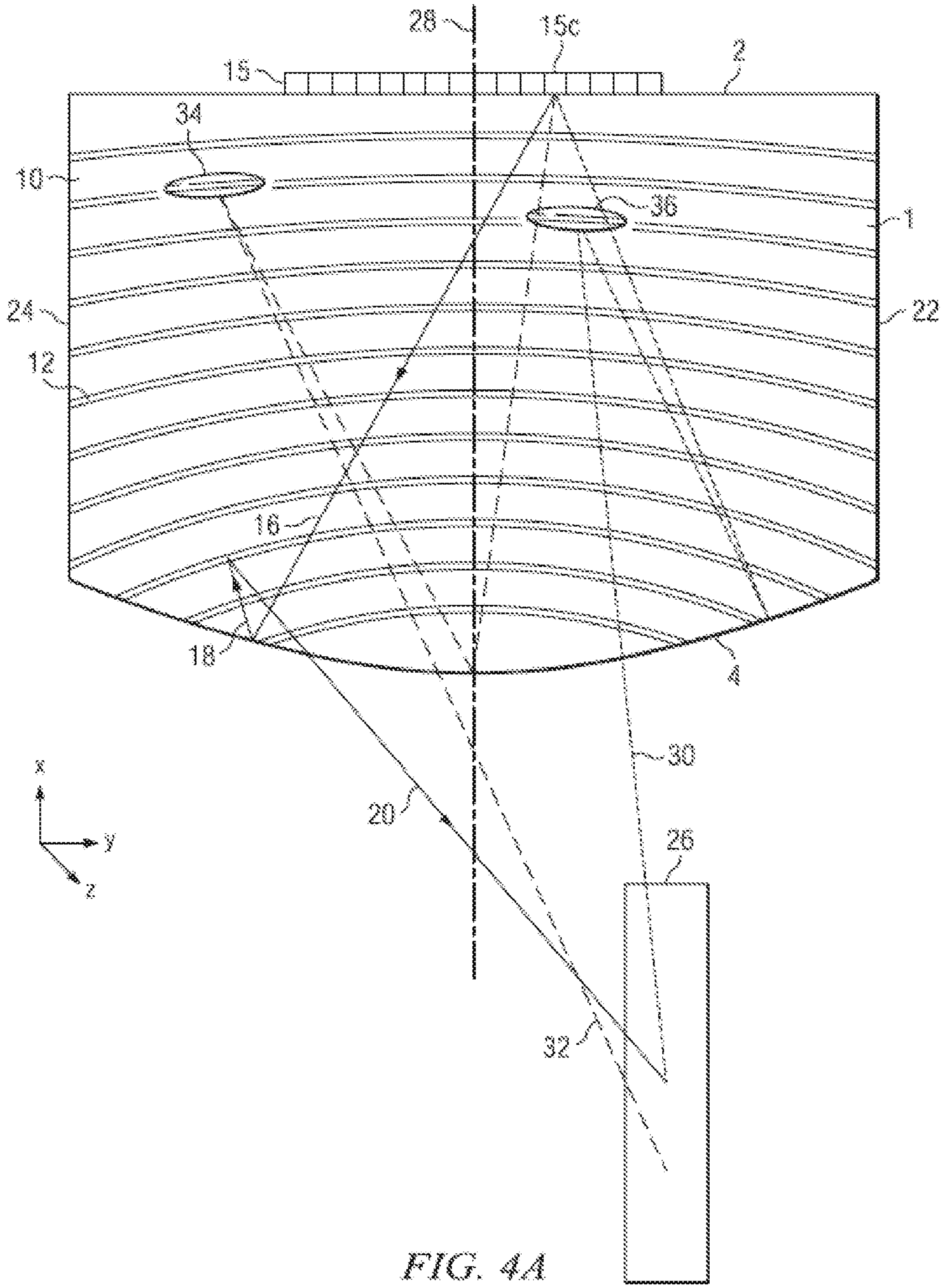

FIG. 4A

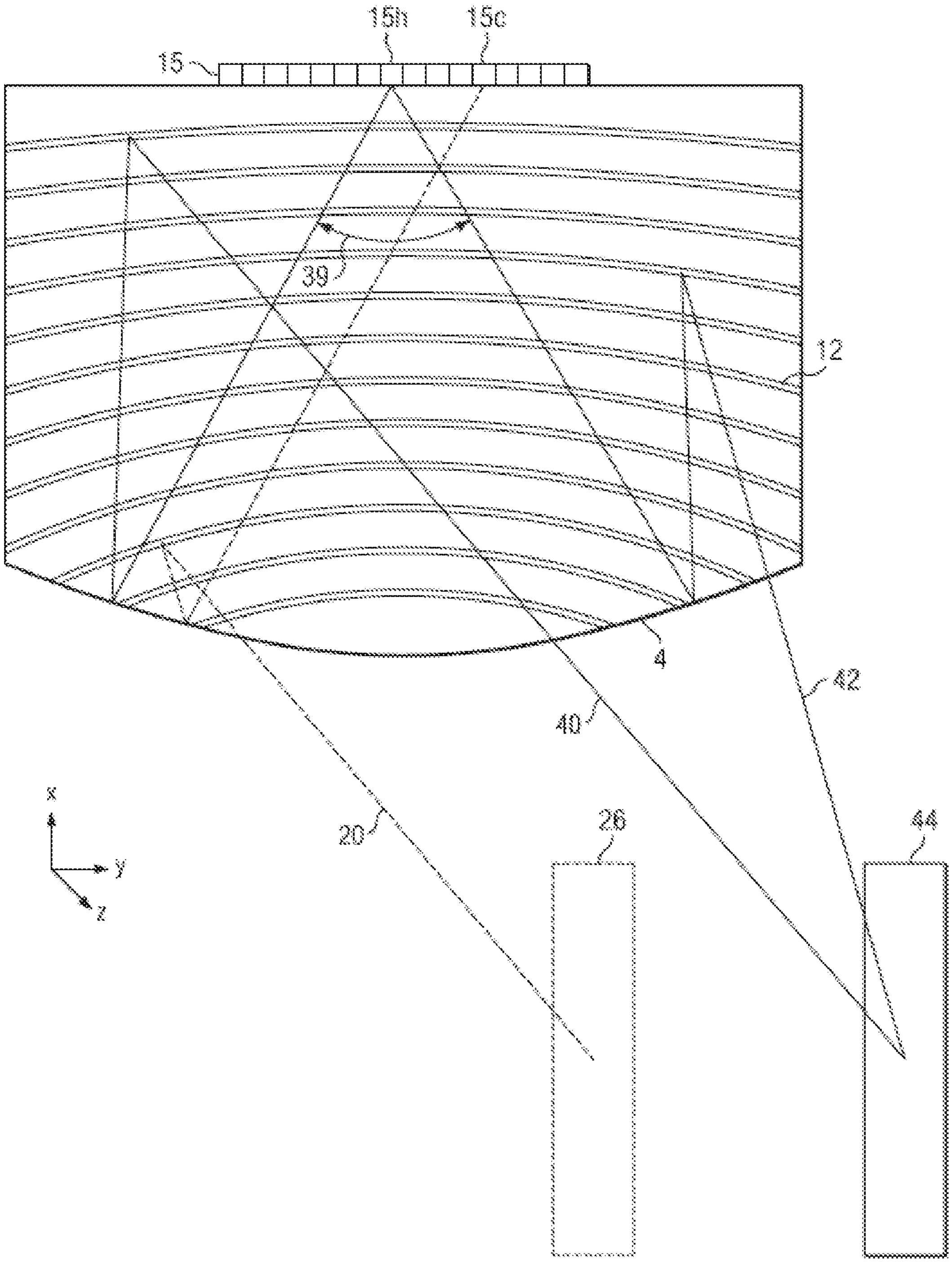

FIG. 4B

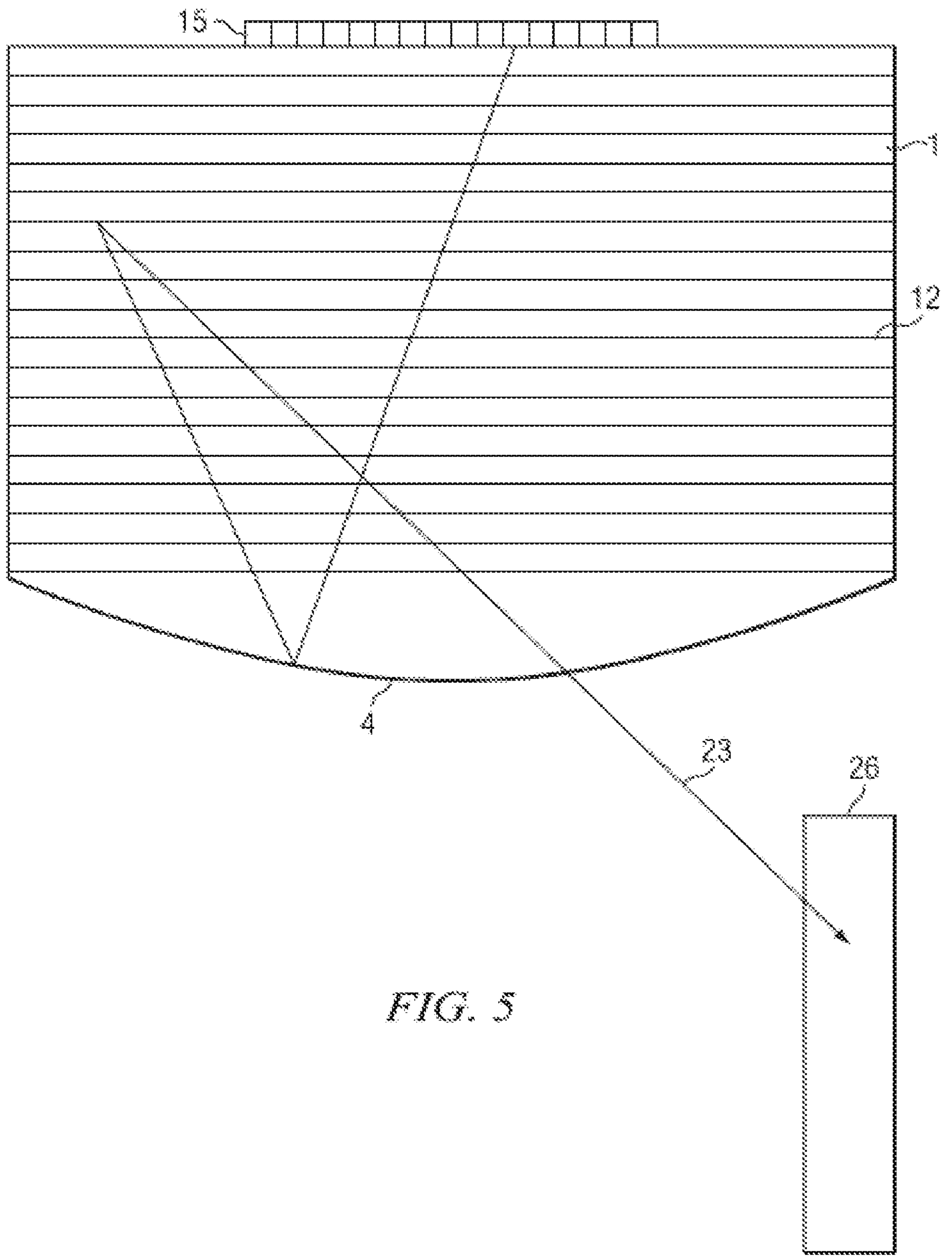

FIG. 5

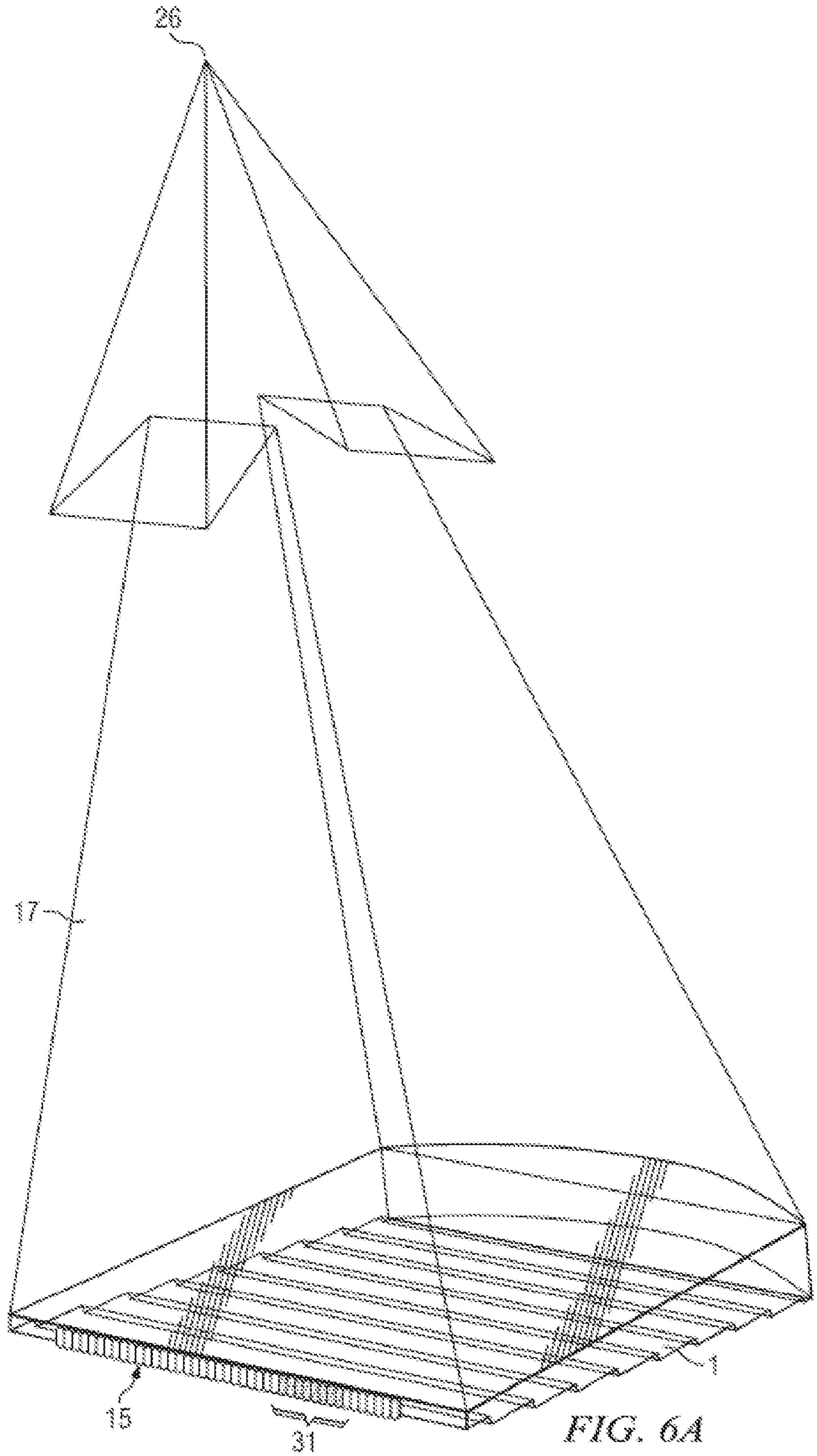

FIG. 6A

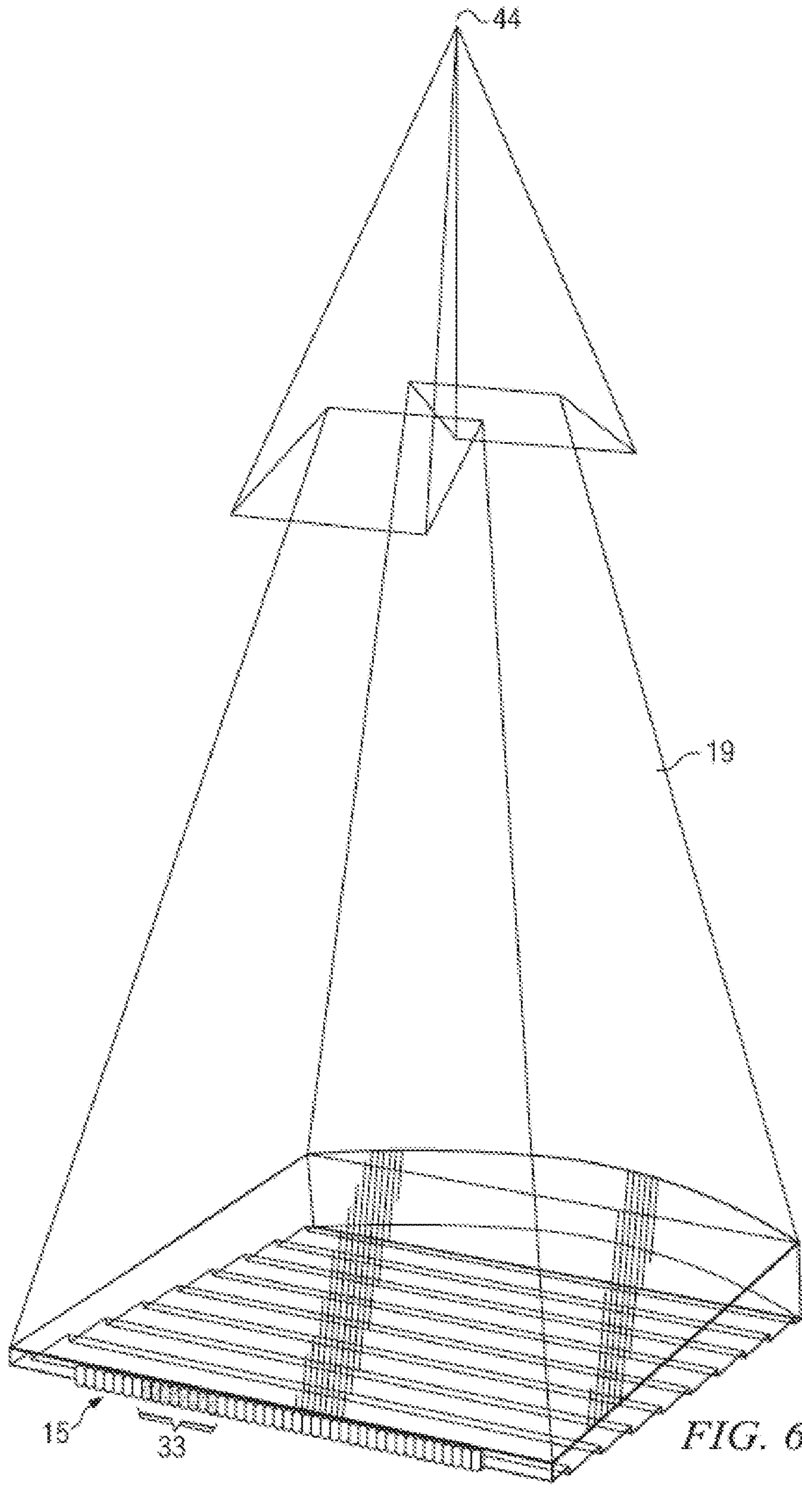

FIG. 6B

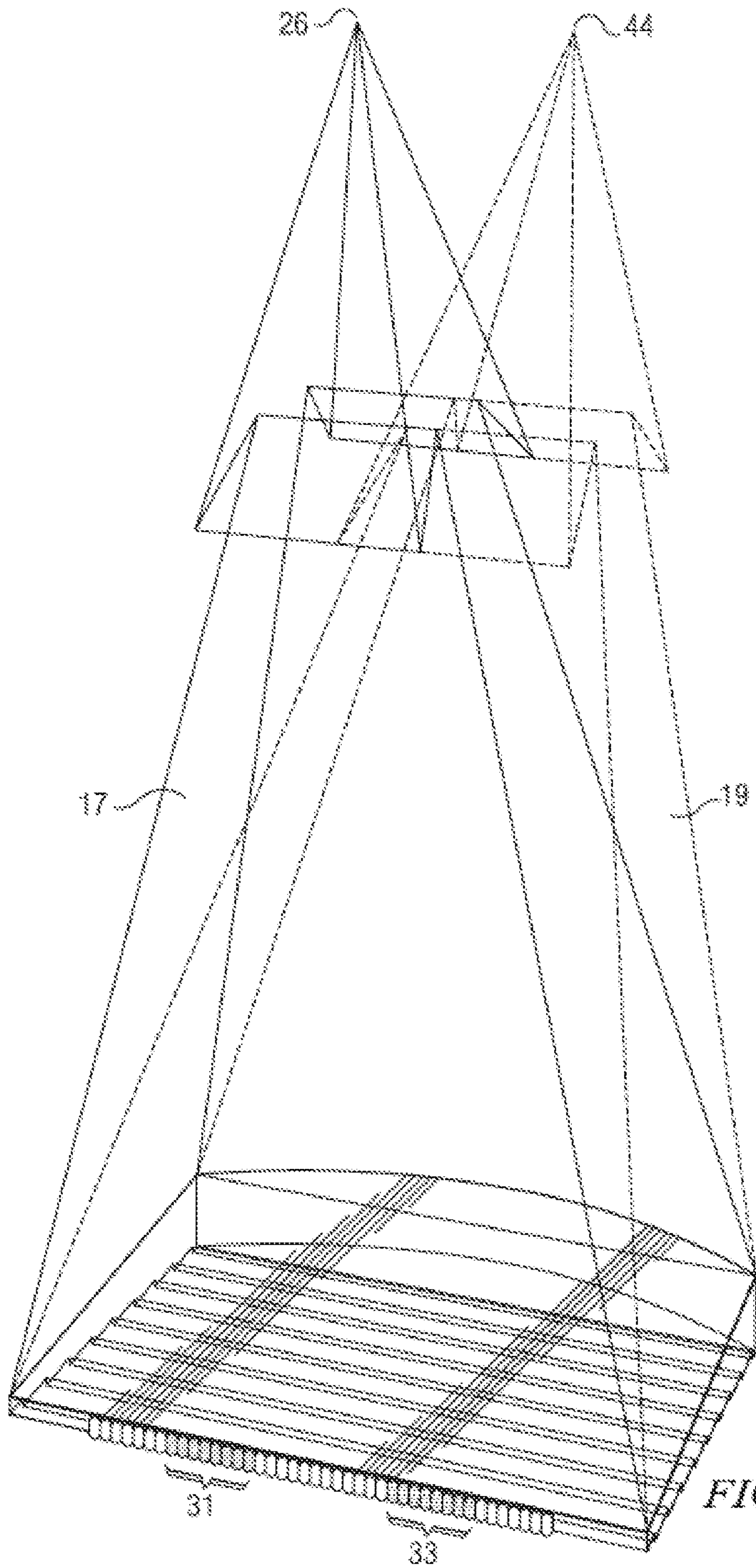

FIG. 6C

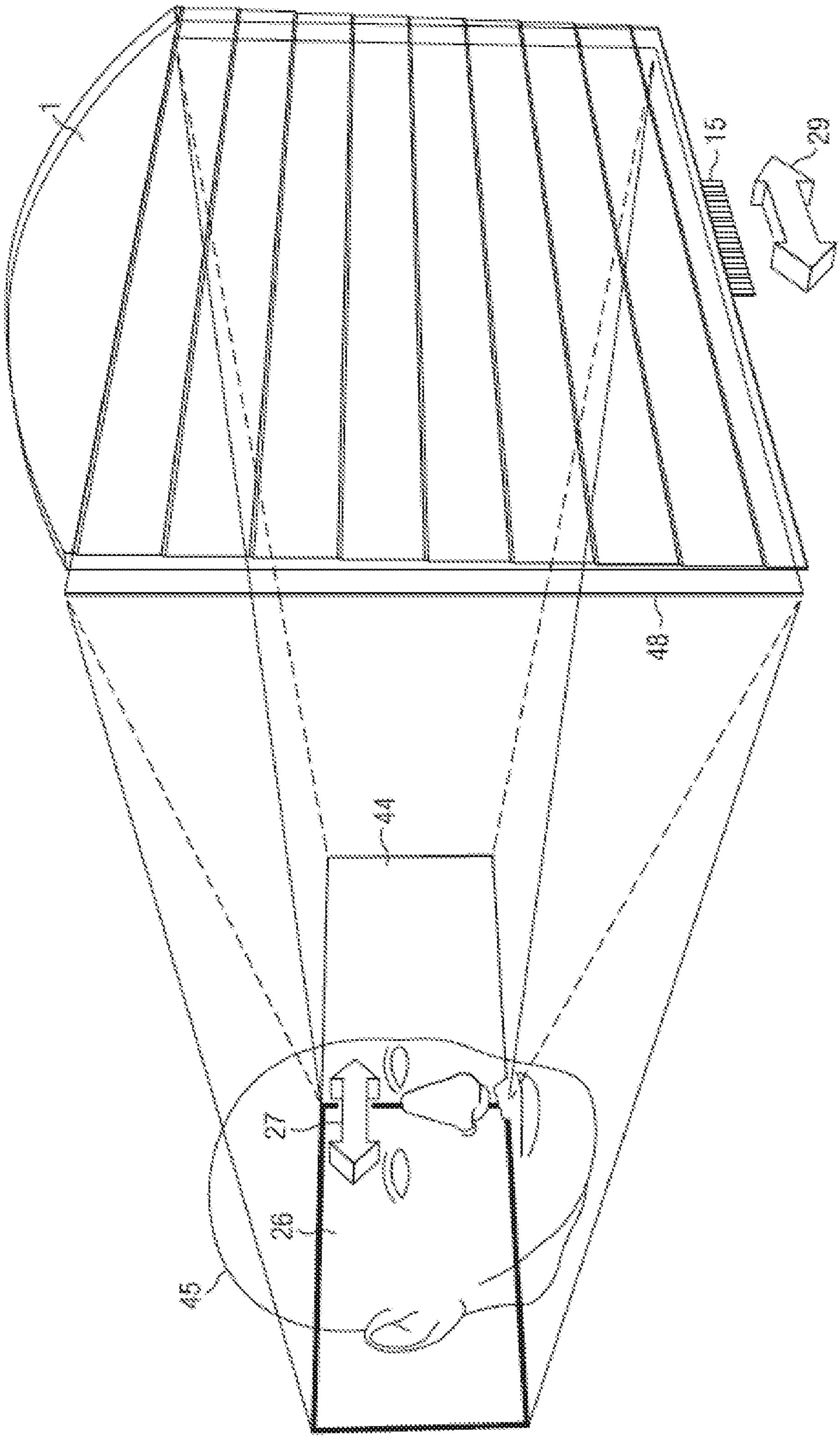

FIG. 7

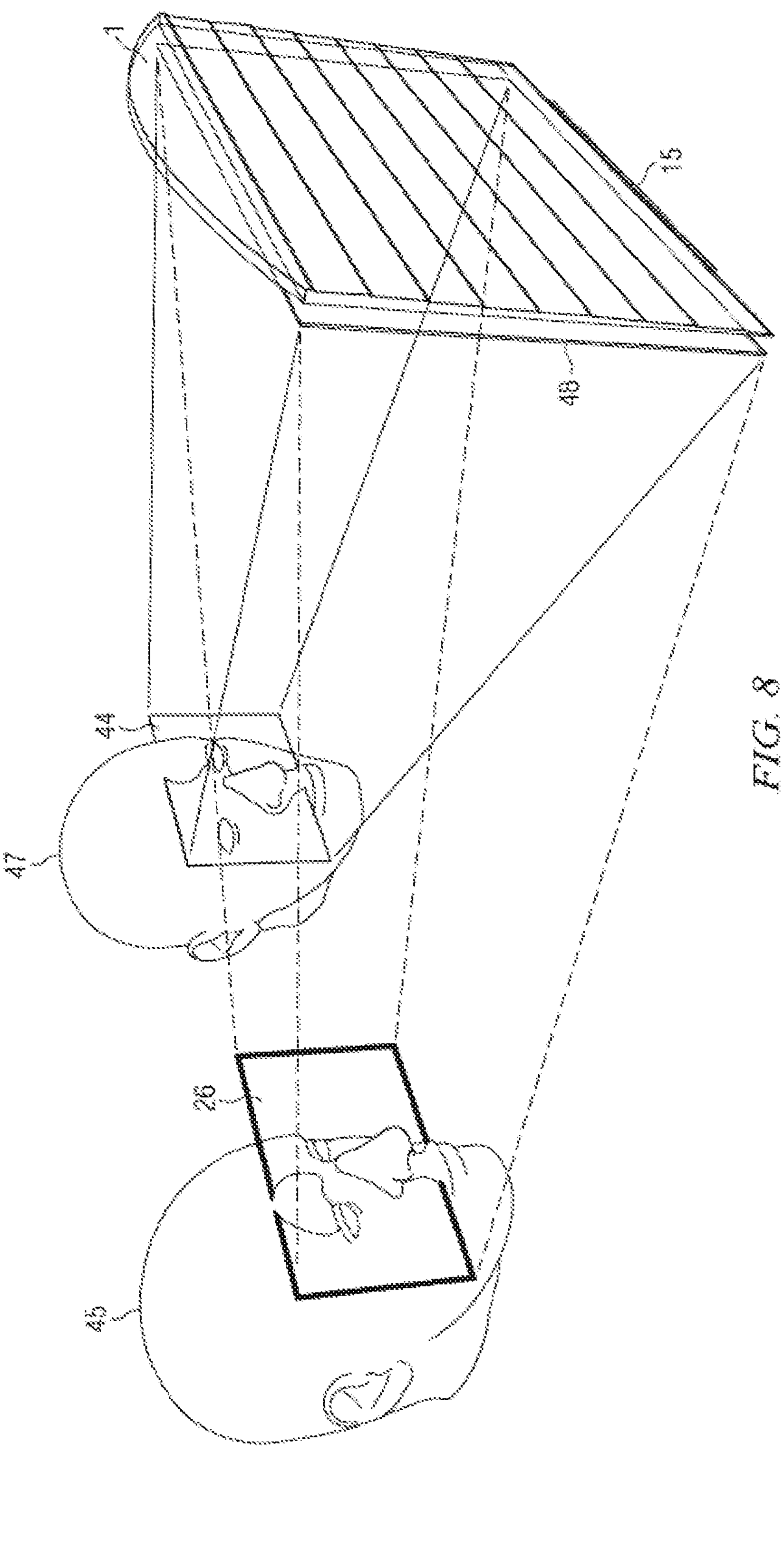

FIG. 8

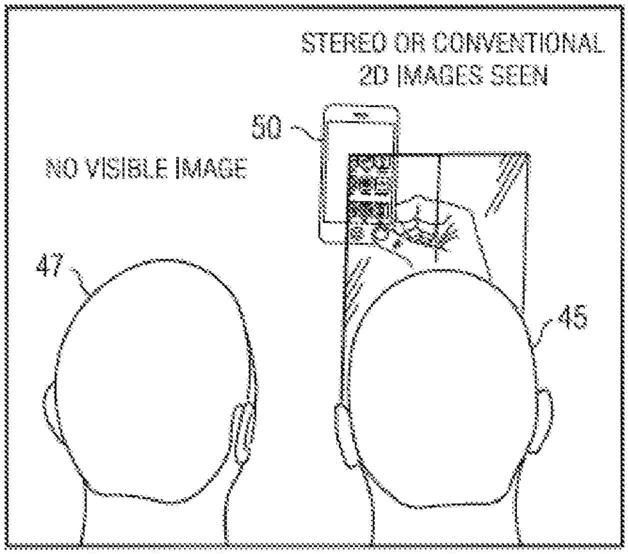
STEREO OR CONVENTIONAL
2D IMAGES SEEN
50
NO VISIBLE IMAGE
47
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FIG. 9

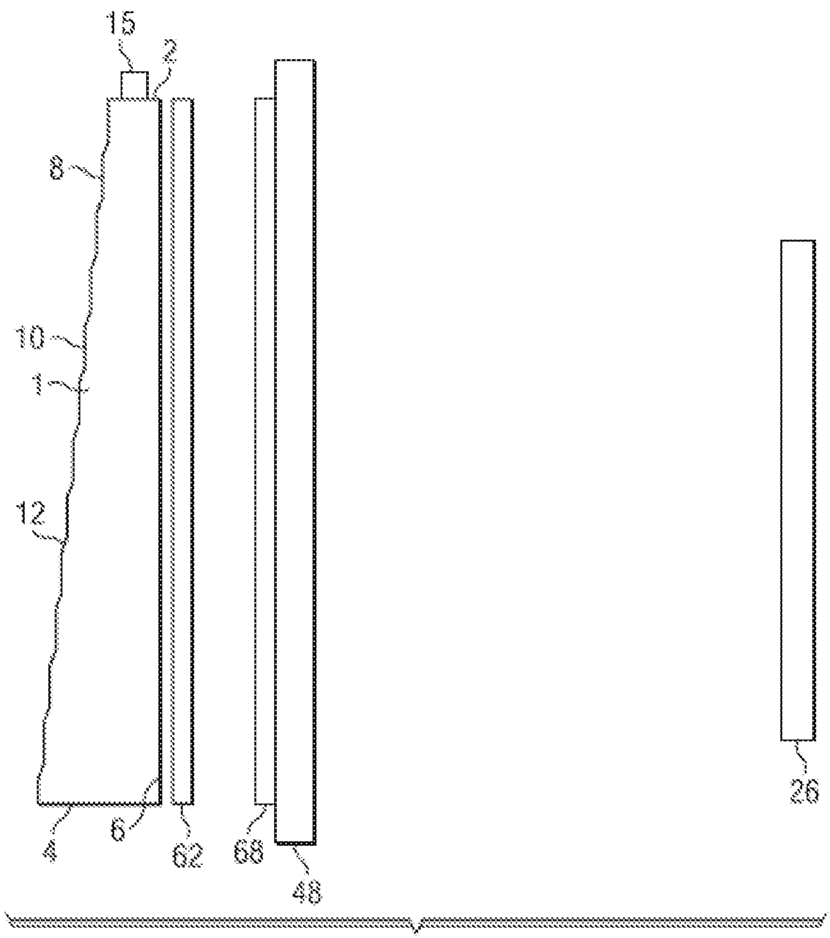
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FIG. 10

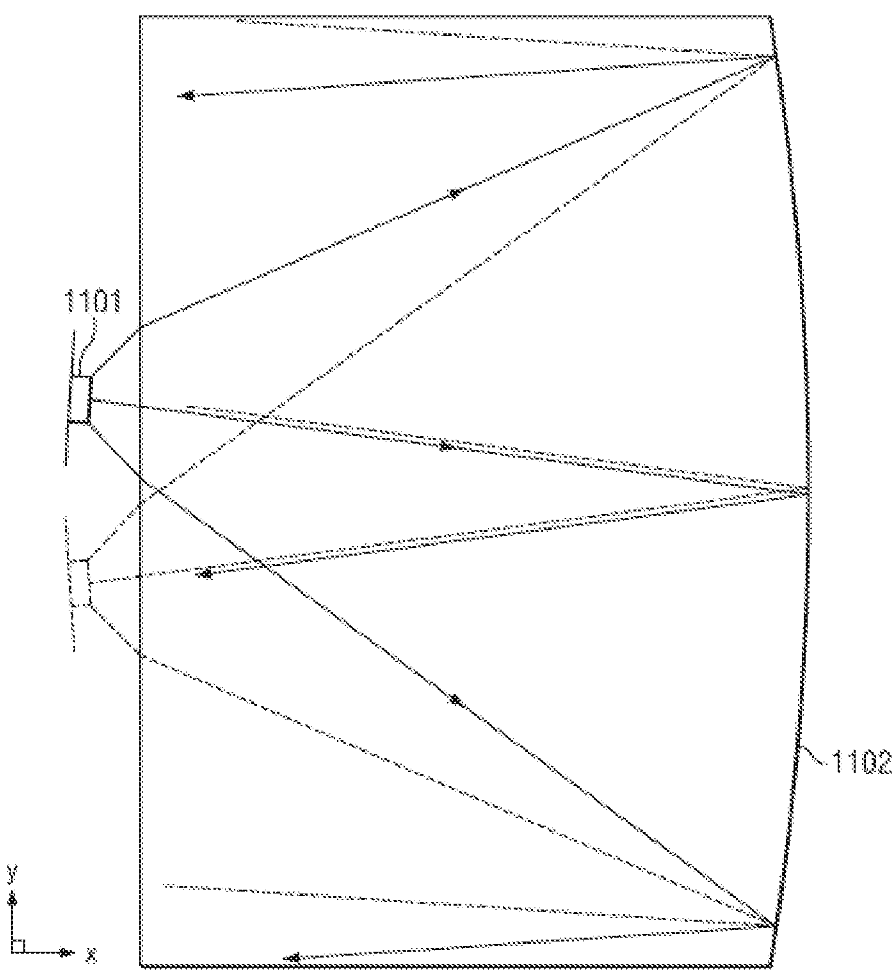


FIG. 11A

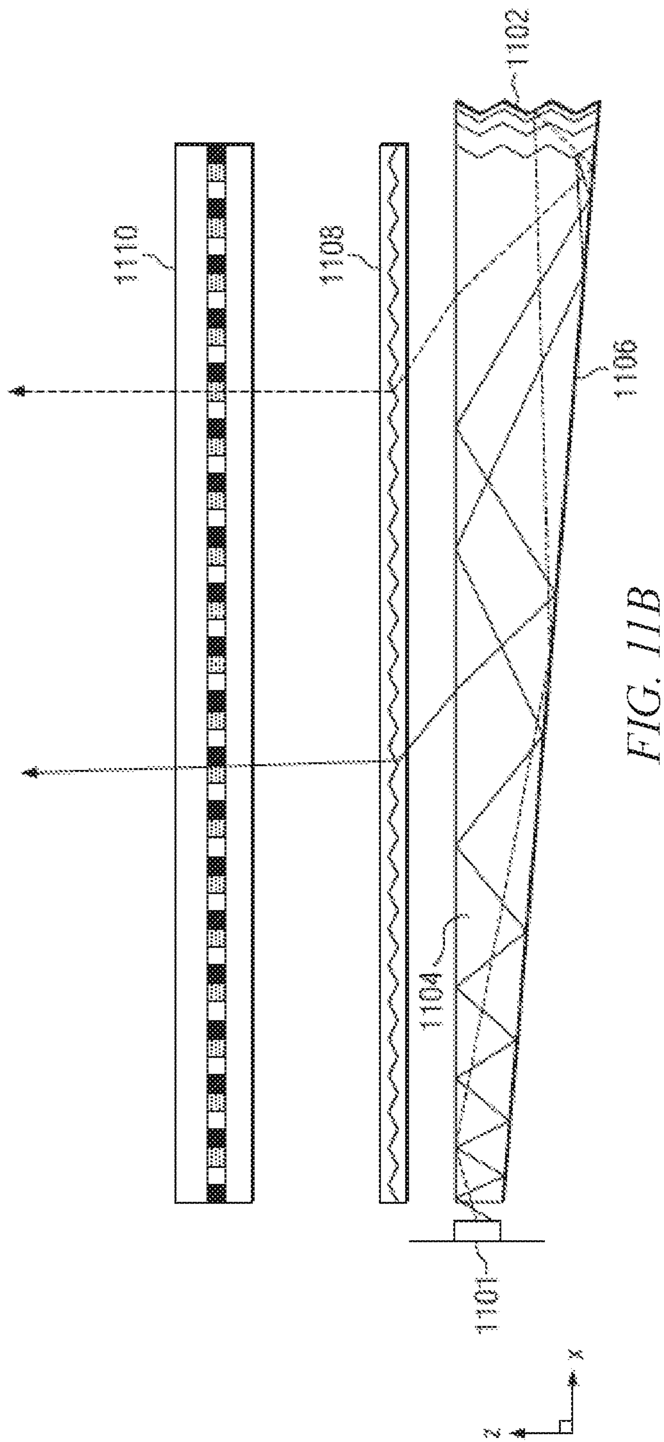


FIG. 11B

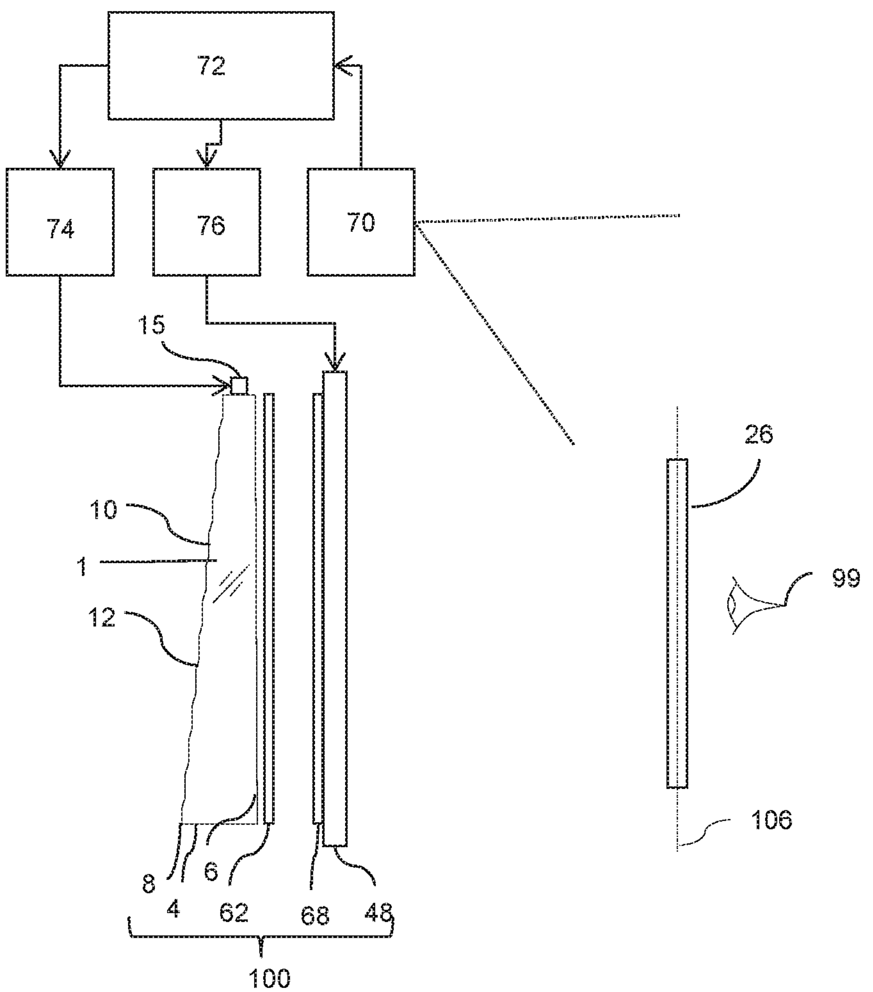


FIG. 12

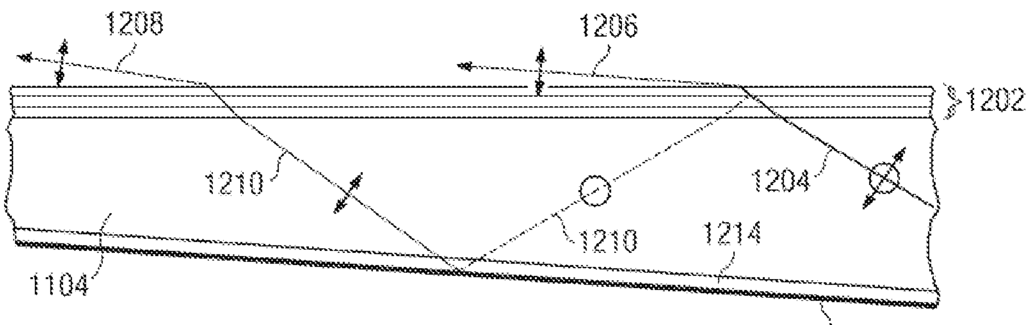


FIG. 13A

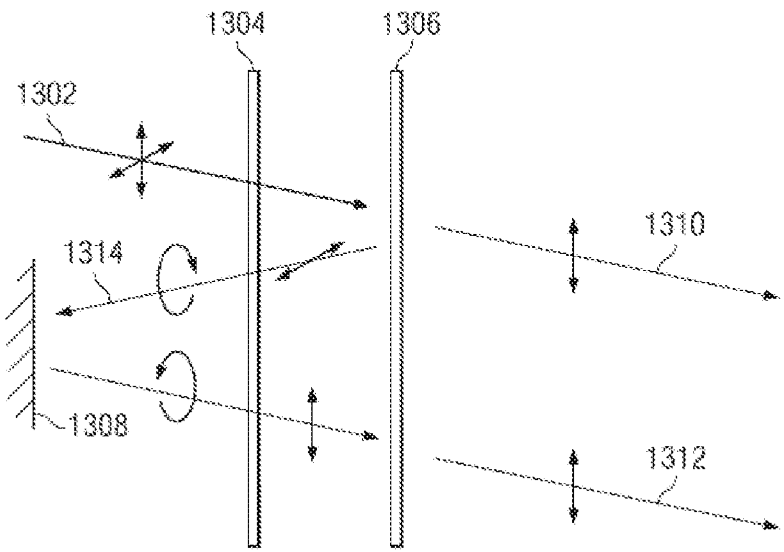


FIG. 13B

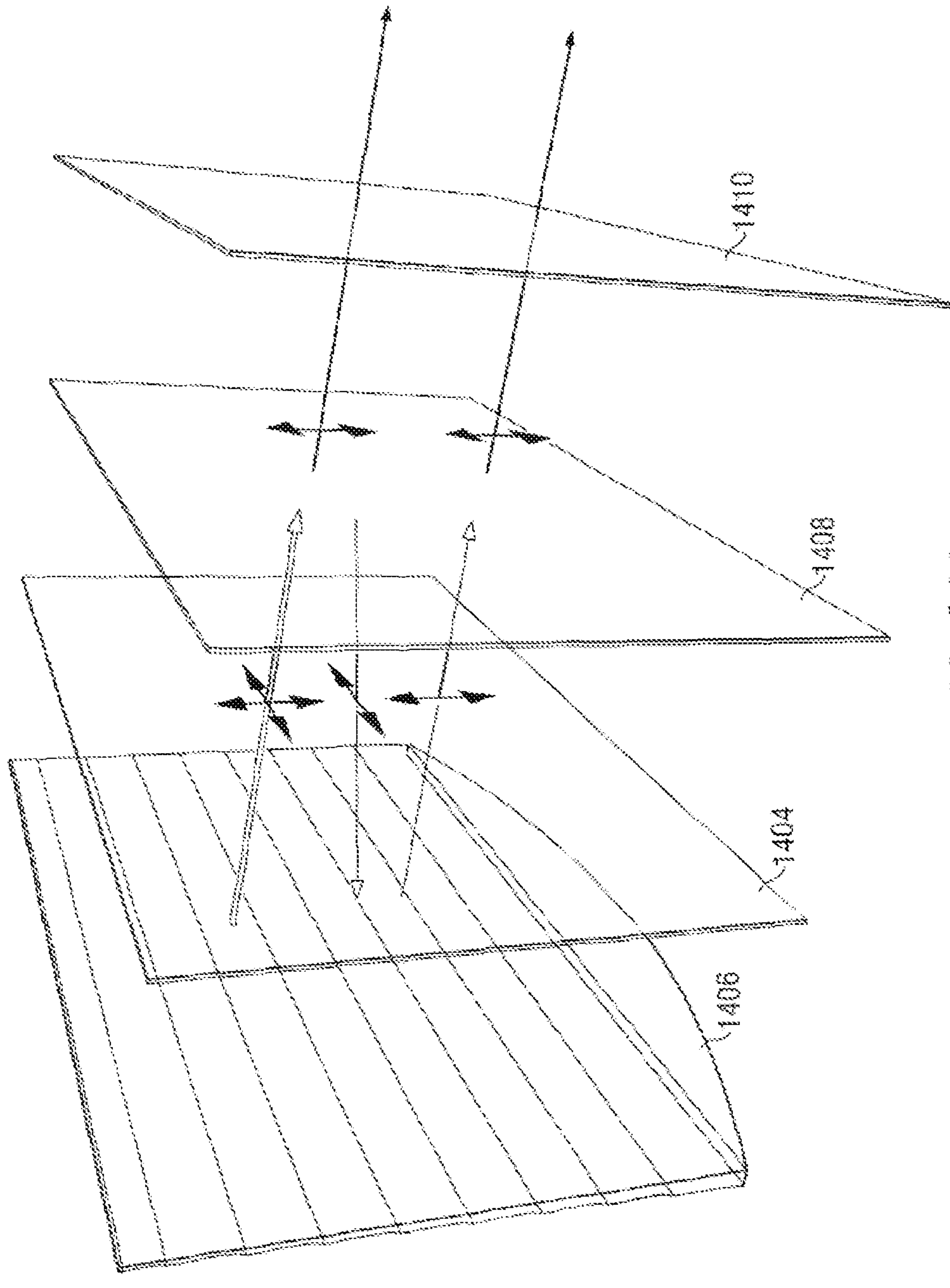
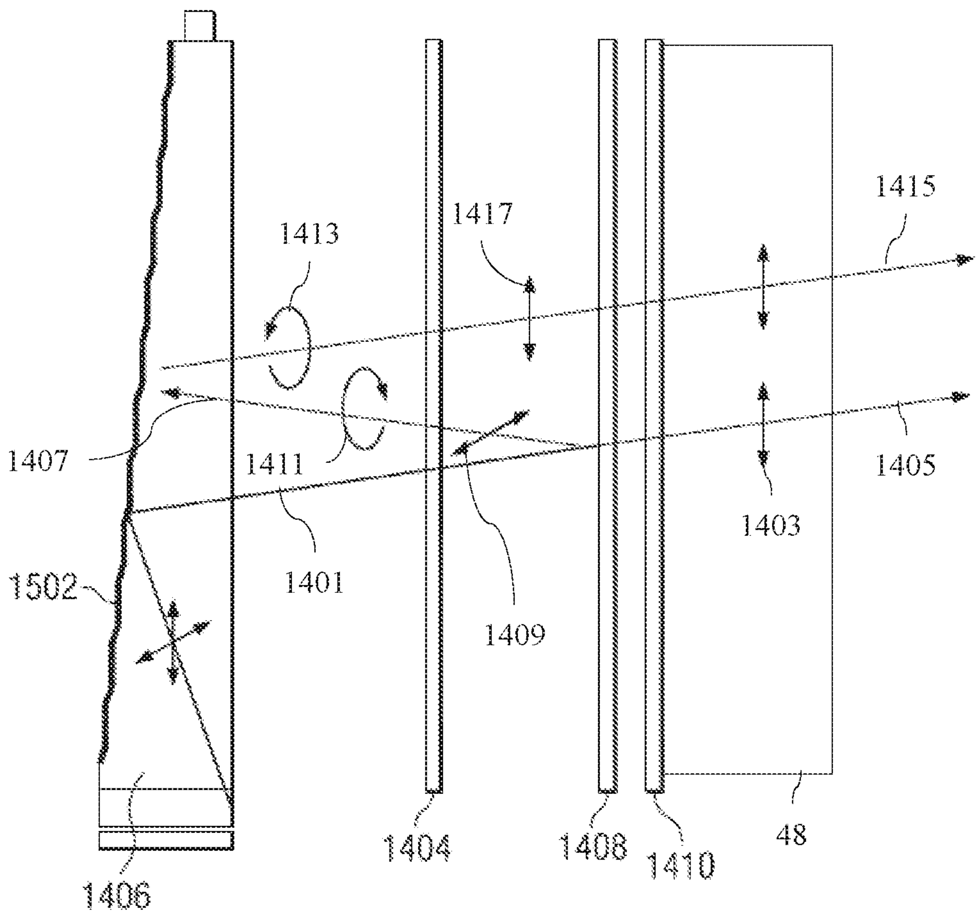


FIG. 14A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1406

FIG. 14B

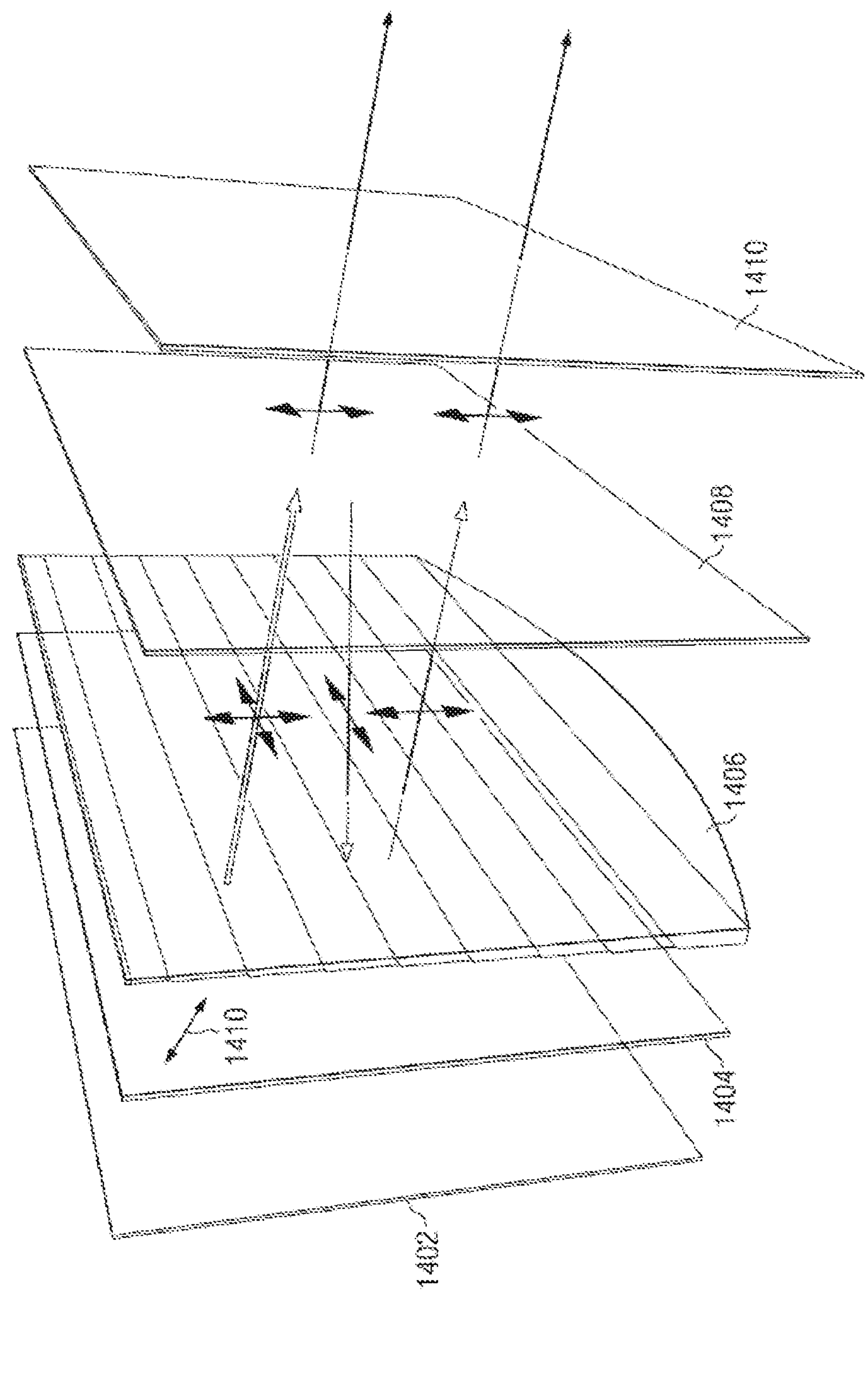

FIG. 15A

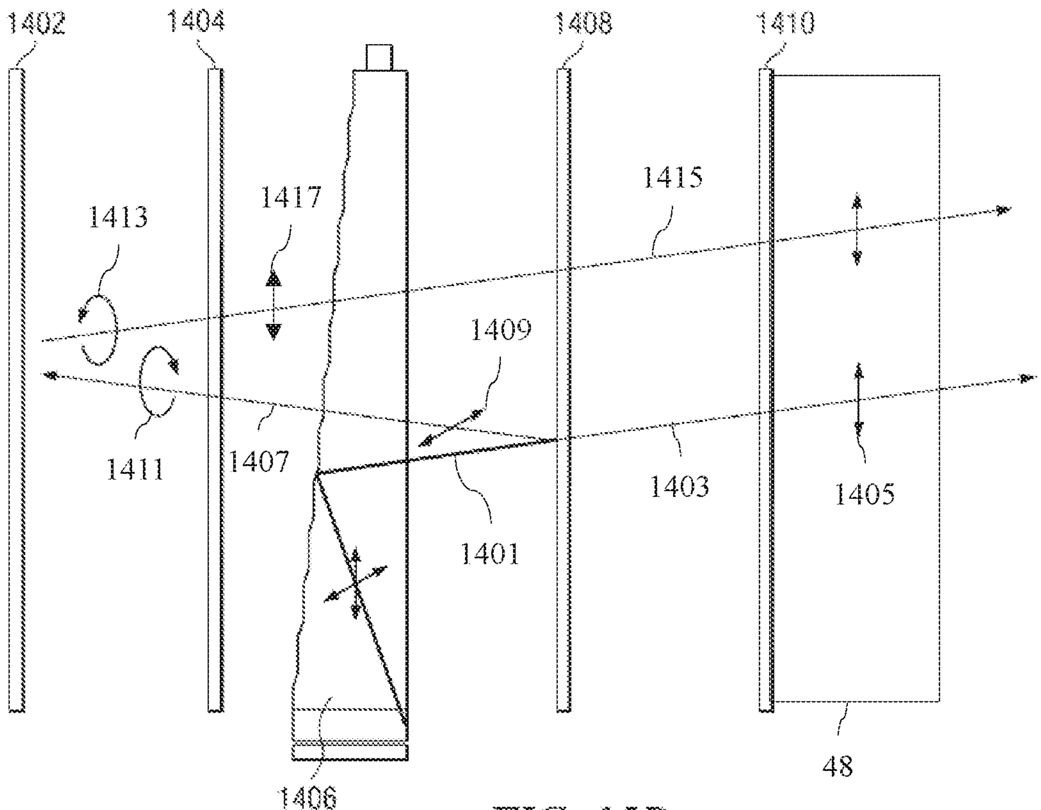
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FIG. 15B

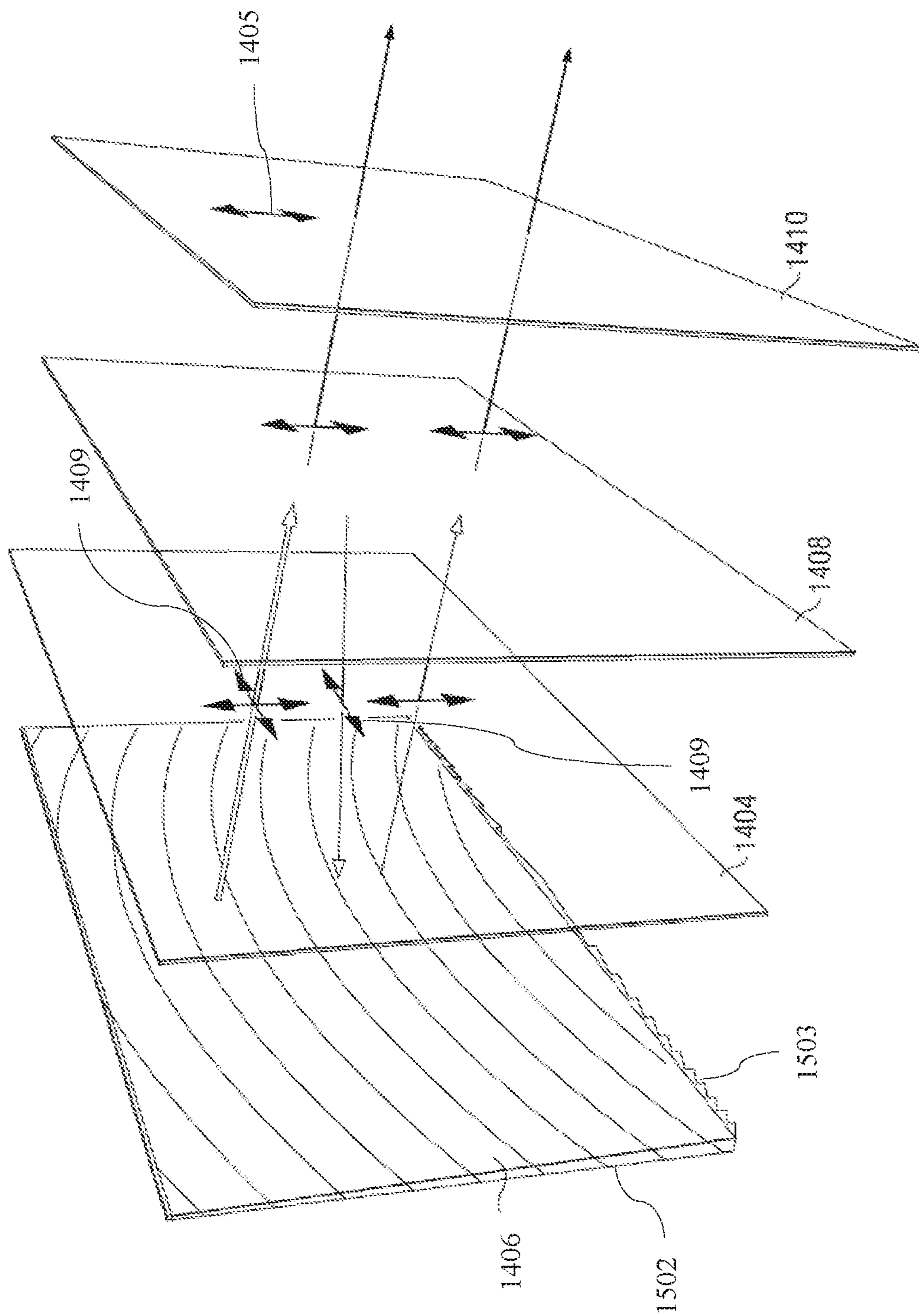

FIG. 16A

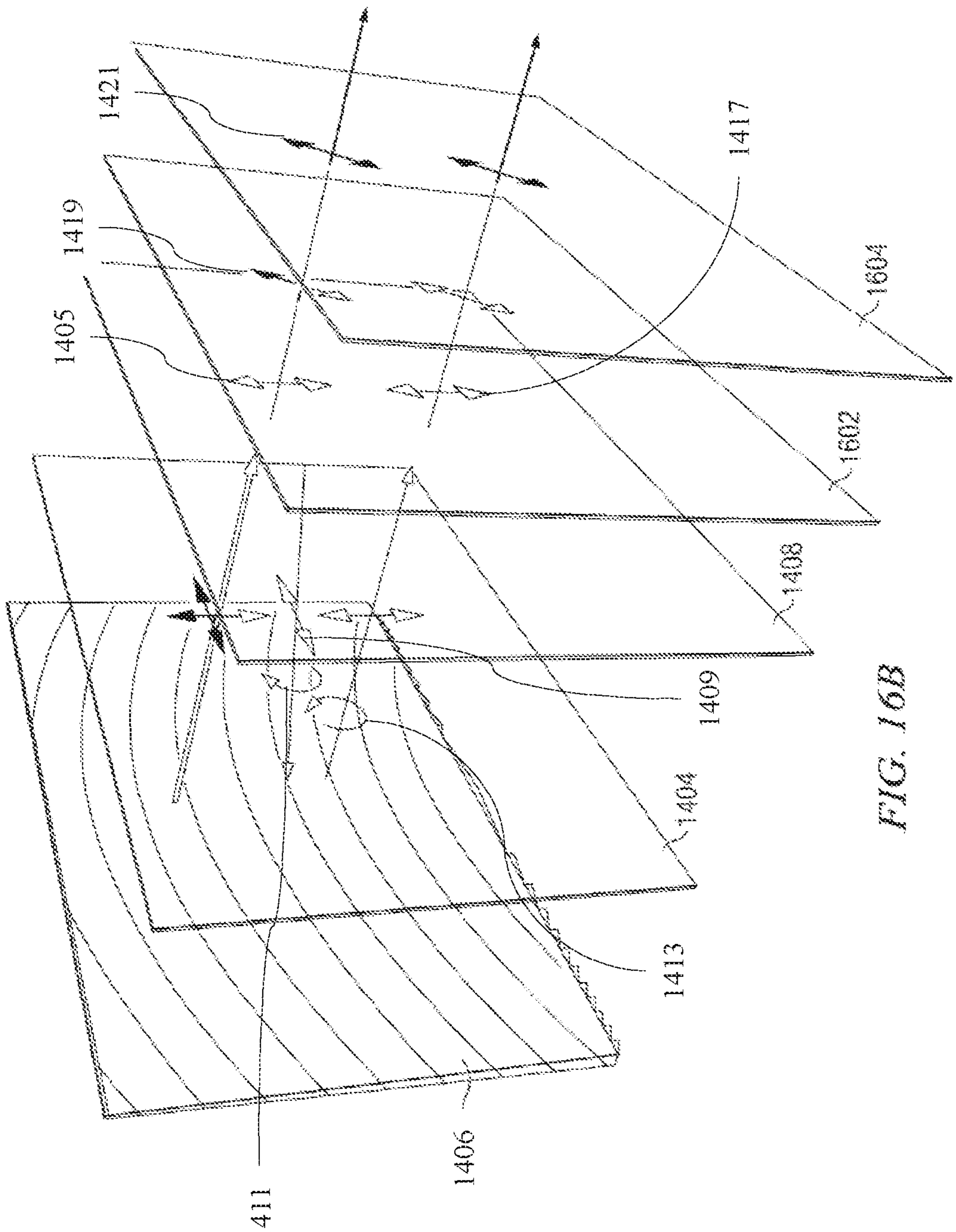

FIG. 16B

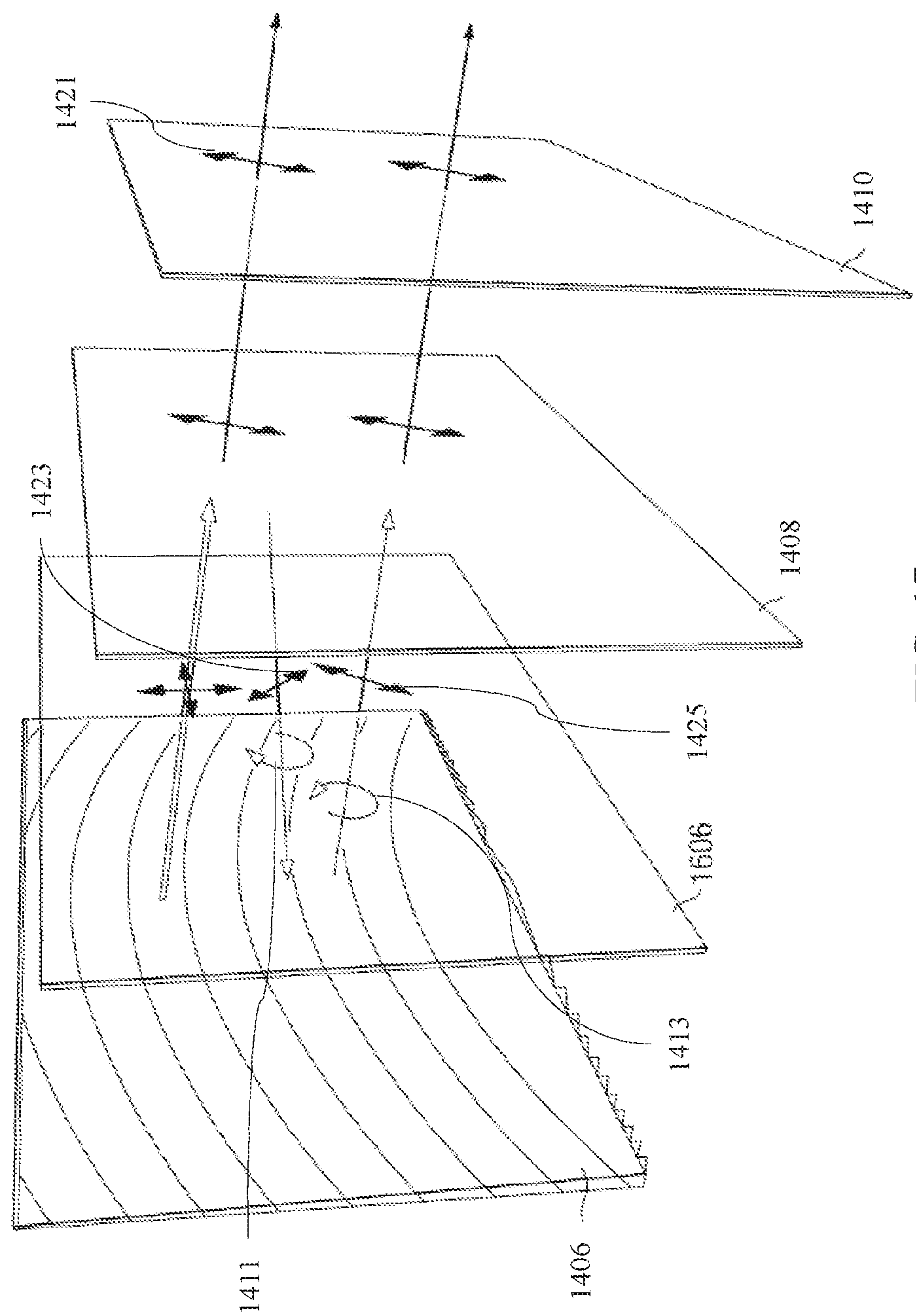

FIG. 17

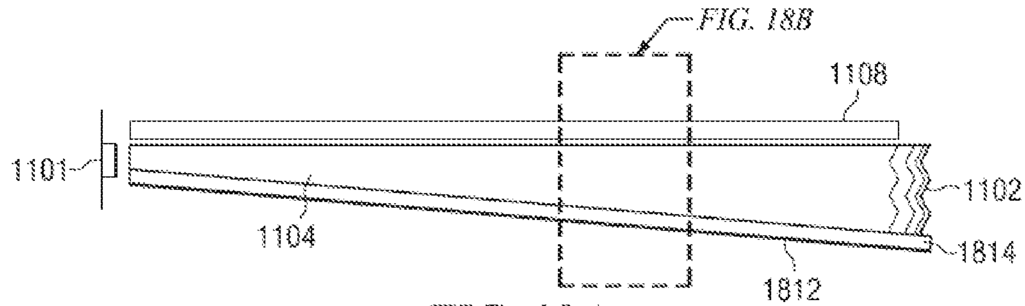

FIG. 18A

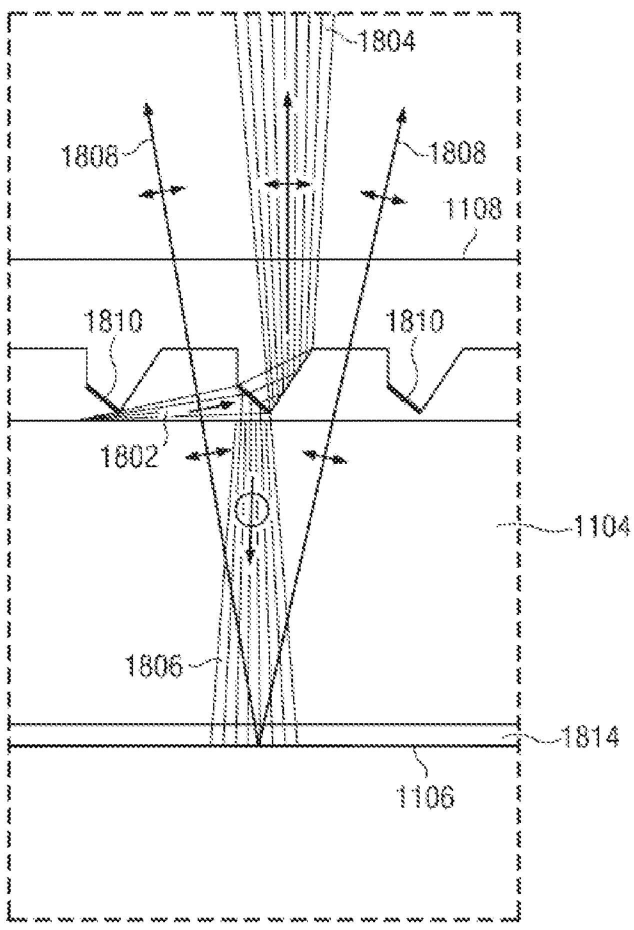

FIG. 18B

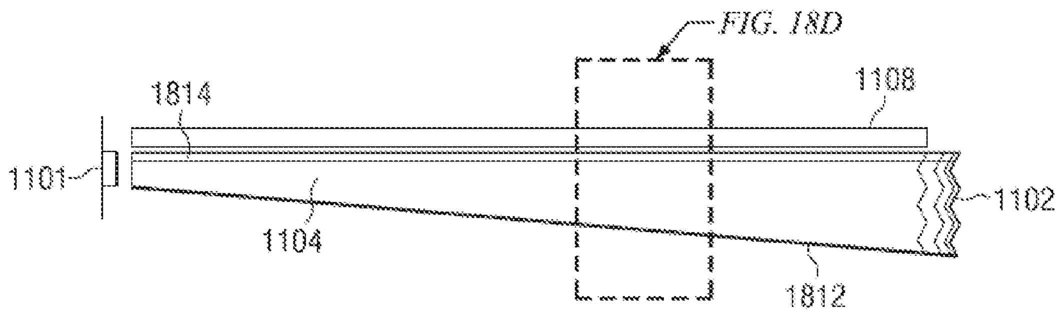

FIG. 18C

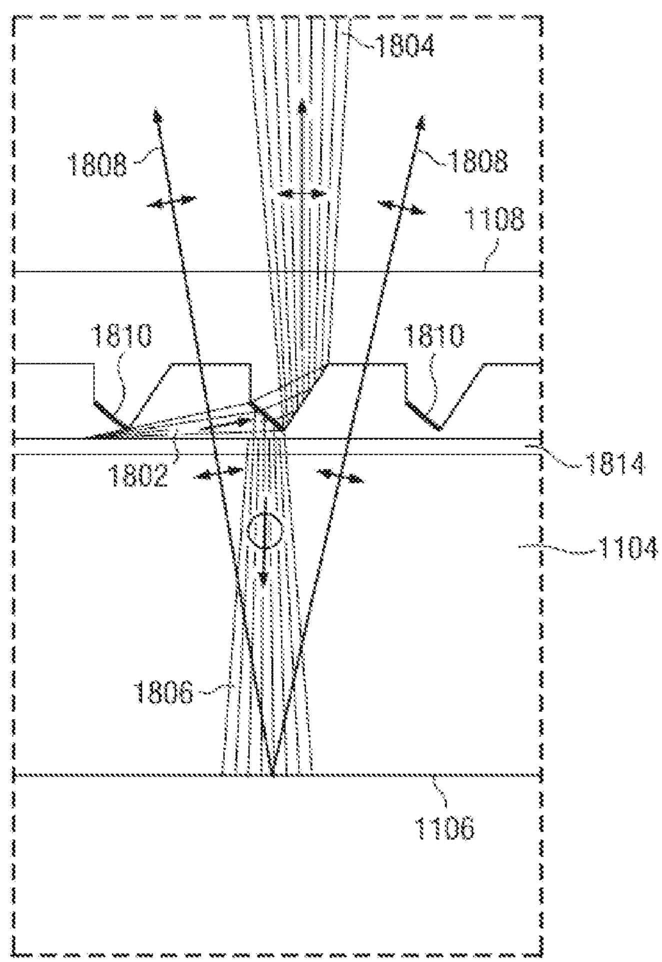

FIG. 18D

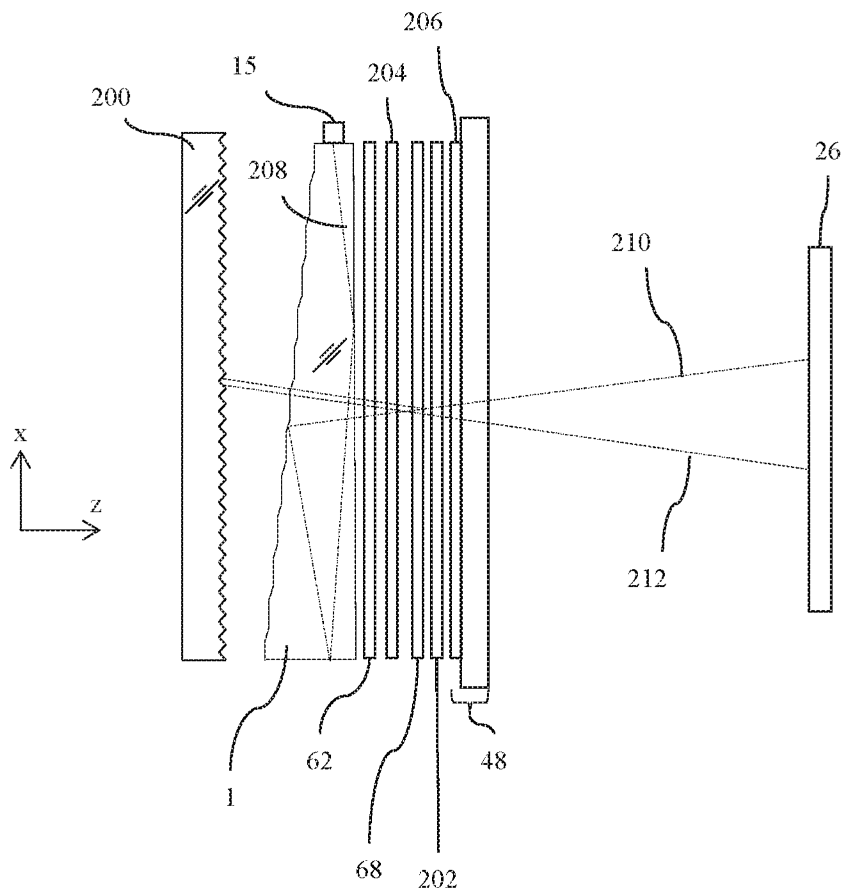

FIG. 19

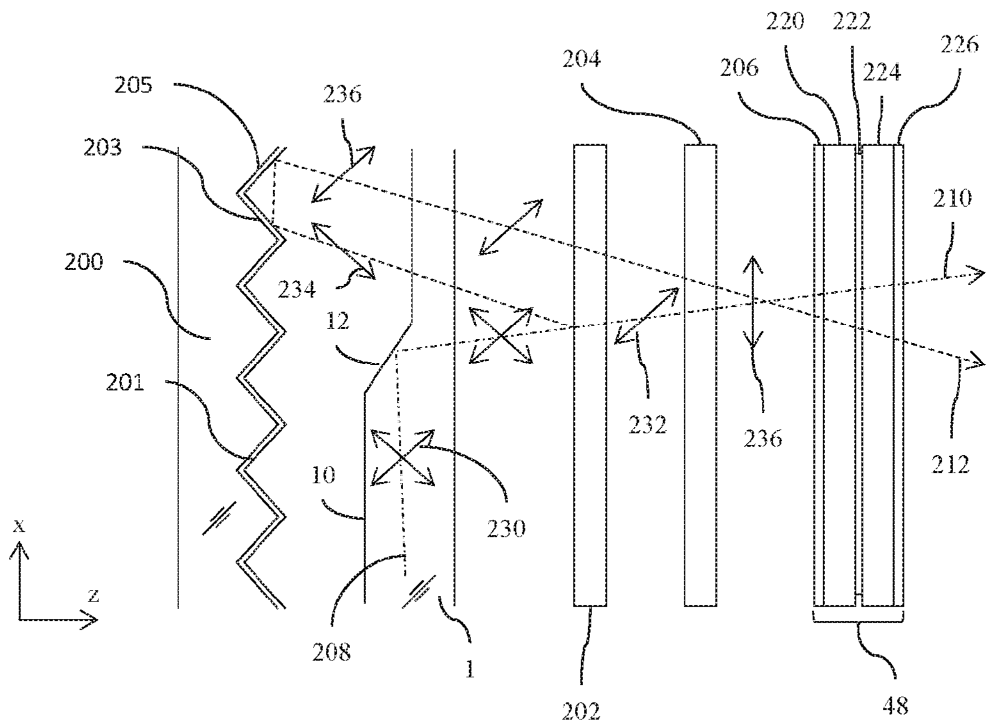

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FIG. 20

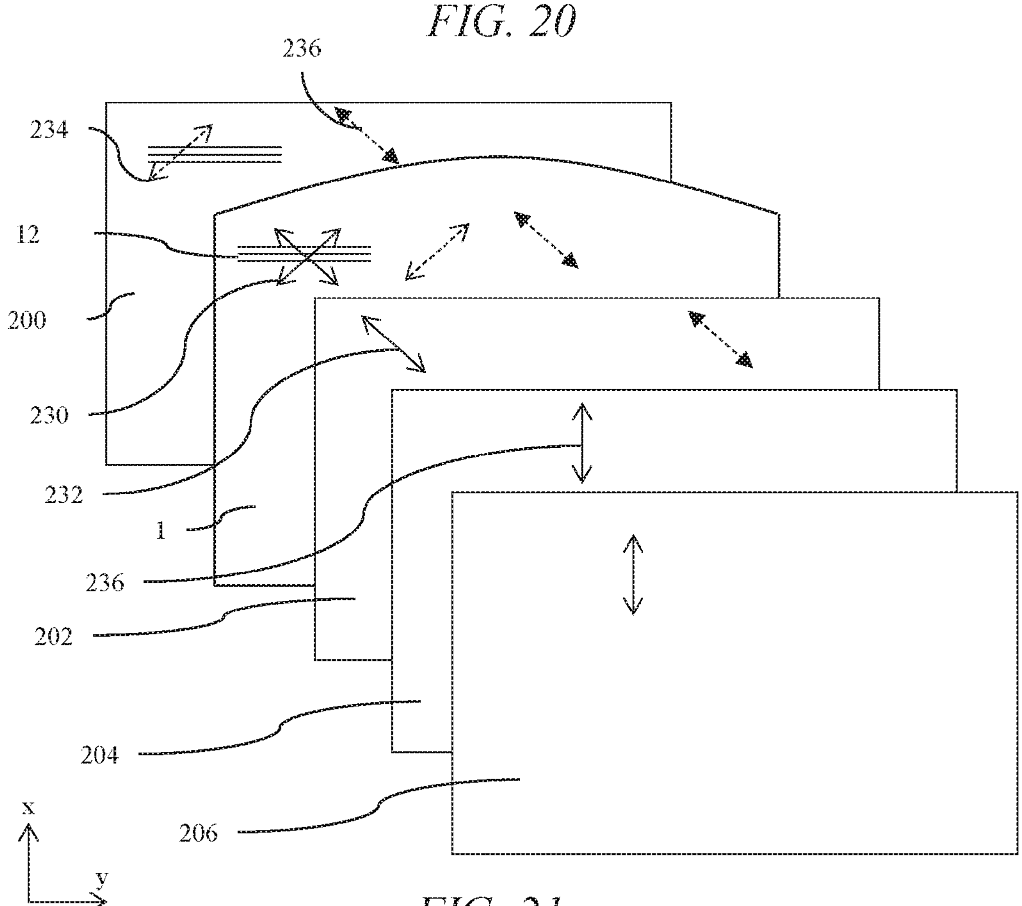

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FIG. 21

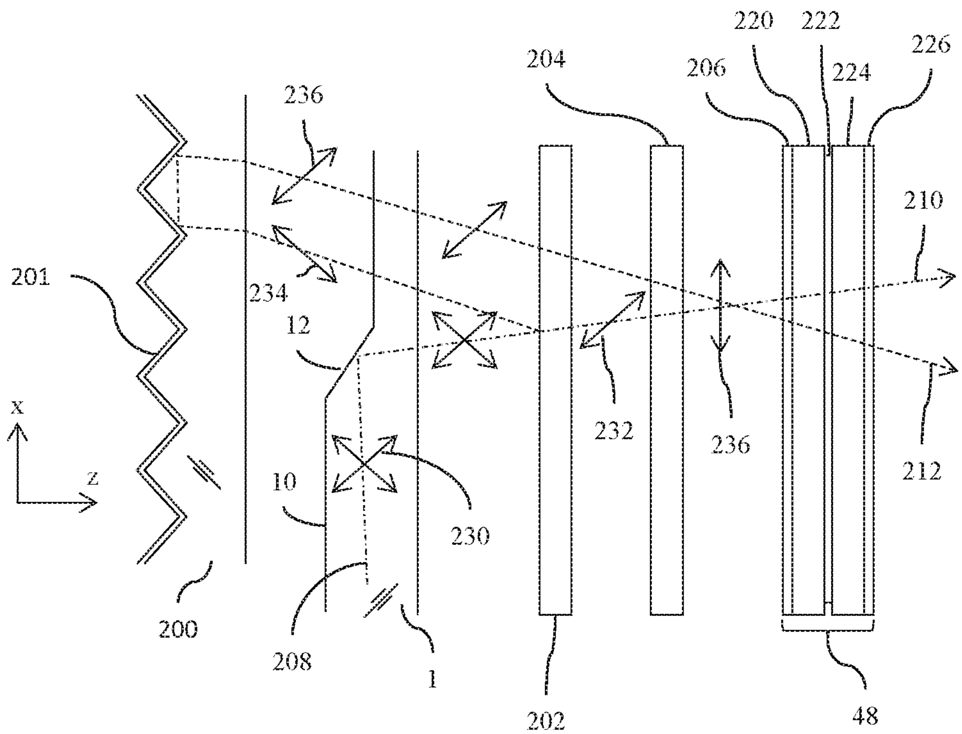
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FIG. 22

POLARIZATION RECOVERY IN A DIRECTIONAL DISPLAY DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 13/837,466 entitled "Polarization recovery in imaging directional backlights", filed Mar. 15, 2013, which claims priority to U.S. Provisional Patent Application No. 61/649,116, entitled "Polarization recovery in imaging directional backlights." filed May 18, 2012, the entirety of which is herein incorporated by reference. Additionally, this application is related to U.S. Provisional Patent Application No. 61/791,112 entitled "Directional Backlight," to Robinson et al., filed on Mar. 15, 2013, which is herein incorporated by reference in its entirety.

TECHNICAL FIELD

This disclosure generally relates to illumination of light modulation devices, and more specifically relates to light guides for providing large area illumination from localized light sources for use in 2D, 3D, and/or autostereoscopic display devices.

BACKGROUND

Spatially multiplexed autostereoscopic displays typically align a parallax component such as a lenticular screen or parallax barrier with an array of images arranged as at least first and second sets of pixels on a spatial light modulator, for example an LCD. The parallax component directs light from each of the sets of pixels into different respective directions to provide first and second viewing windows in front of the display. An observer with an eye placed in the first viewing window can see a first image with light from the first set of pixels; and with an eye placed in the second viewing window can see a second image, with light from the second set of pixels.

Such displays have reduced spatial resolution compared to the native resolution of the spatial light modulator and further, the structure of the viewing windows is determined by the pixel aperture shape and parallax component imaging function. Gaps between the pixels, for example for electrodes, typically produce non-uniform viewing windows. Undesirably such displays exhibit image flicker as an observer moves laterally with respect to the display and so limit the viewing freedom of the display. Such flicker can be reduced by defocusing the optical elements; however such defocusing results in increased levels of image cross talk and increases visual strain for an observer. Such flicker can be reduced by adjusting the shape of the pixel aperture, however such changes can reduce display brightness and can include addressing electronics in the spatial light modulator.

BRIEF SUMMARY

According to a first aspect of the present disclosure, there is provided a directional display device which may include a waveguide having an input end. The directional display device may also include an array of light sources disposed at different input positions across the input end of the waveguide. The waveguide may further include first and second, opposed guide surfaces for guiding light along the waveguide. The first guide surface may be arranged to guide light by total internal reflection. The second guide surface

may include light extraction features oriented to reflect light guided through the waveguide in directions allowing exit through the first guide surface as output light and intermediate regions between the light extraction features that are arranged to direct light through the waveguide without extracting it. The waveguide may be arranged to direct input light from different light sources through the first guide surface as the output light into respective optical windows in output directions distributed in the lateral direction in dependence on the input. The directional display device may also include a transmissive spatial light modulator which may be arranged to receive the output light from the first guide surface and arranged to modulate a first polarization component of the output light having a first polarization. The directional display device may also include a reflective polarizer which may be disposed between the first guide surface of the waveguide and the spatial light modulator and arranged to transmit the first polarization component and to reflect a second polarization component of the output light having a polarization orthogonal to the first polarization as rejected light. Further, the directional display device may also include a rear reflector which may be disposed behind the second guide surface arranged to reflect the rejected light for supply back to the spatial light modulator, the directional display device further being arranged to convert the polarization of the rejected light supplied back to spatial light modulator into the first polarization.

Advantageously the present embodiments may achieve increased utilization of light in systems using a transmissive spatial light modulator requiring polarised input light. Display brightness may be increased, battery lifetime may be extended and the display may be used in brighter ambient environments. Further, the viewing windows may be provided for light from the backlight that is of both incident polarisation states so that the display has high brightness in a directional mode of operation. Thus a high brightness efficient directional display that may be provided for autostereoscopic 3D display, privacy display and high efficiency 2D displays.

According to a further aspect of the present disclosure, there may be provided a polarized directional illumination apparatus, which may include an imaging directional backlight. The imaging directional backlight may include a waveguide for guiding light. The waveguide may include a first light guiding surface operable to direct light from an illuminator array in a first direction and a second light guiding surface, operable to allow light to exit the waveguide, and a light input surface operable to receive light from the illuminator array, and a polarization sensitive reflector proximate to the first light guiding surface of the waveguide and for providing at least polarization selective reflection.

According to a further aspect of the present disclosure, there may be provided an imaging directional backlight which may include an input side located at a first end of a waveguide, wherein the input side is operable to receive light from at least an illuminator array, a reflective side located at a second end of the waveguide, a first light directing side and a second light directing side located between the input side and the reflective side of the waveguide. The second light directing side may be operable to allow light to exit the waveguide. The imaging directional backlight may also include a polarization sensitive reflector proximate to the first light directing side of the waveguide and for providing at least polarization selective reflection.

According to a further aspect of the present disclosure, there may be provided an optical valve system that provides polarization recovery, which may include a waveguide for guiding light. The waveguide may include a first light guiding surface and a second light guiding surface, opposite the first light guiding surface. The waveguide may further include at least one guiding feature and a plurality of extraction features. The plurality of extraction features may allow light to pass with substantially low loss when the light is propagating in a first direction and allow light to exit the waveguide upon encountering at least a first extraction feature of the plurality of extraction features. The optical valve system may include a spatial light modulator which may be proximate to the waveguide and a polarization sensitive reflector proximate to the first light directing side of the waveguide and for providing at least polarization selective reflection.

According to other aspects of the present disclosure, a polarized directional illumination apparatus may include an imaging directional backlight and a reflective polarizer proximate to the first light guiding surface of the waveguide and for providing at least polarization selective reflection. The imaging directional backlight may include a waveguide for guiding light. The waveguide may include a first light guiding surface operable to direct light from an illuminator array in a first direction, a second light guiding surface, operable to allow light to exit the waveguide, and a light input surface operable to receive light from the illuminator array.

Display backlights in general employ waveguides and edge emitting sources. Certain imaging directional backlights have the additional capability of directing the illumination through a display panel into viewing windows. An imaging system may be formed between multiple sources and the respective window images. One example of an imaging directional backlight is an optical valve that may employ a folded optical system and hence may also be an example of a folded imaging directional backlight. Light may propagate substantially without loss in one direction through the optical valve while counter-propagating light may be extracted by reflection off tilted facets as described in U.S. patent application Ser. No. 13/300,293, which is herein incorporated by reference, in its entirety.

In general with directional backlight systems, the illuminating light is unpolarized resulting in at least 50% loss of the light in the conventional sheet pre-polarizer of an LCD system. In some conventional backlight units, the light of the incorrect polarization can be recovered by using a reflective sheet polarizer to direct the light back into the diffuse reflecting, polarization mixing elements of the structure. A greater efficiency can be expected in imaging directional backlight systems modified for polarization recovery by virtue of the controlled nature of the light's propagation.

In one embodiment, a reflecting polarizer layer directs light of an undesired polarization state back through the waveguide portion of an imaging directional backlight. This light may be transformed in polarization before being reflected back though the reflecting polarizer and adds to the now substantially uniformly polarized illuminating beam.

In another aspect of this invention, unpolarized light sources may be independently coupled to localized polarization recovery systems which may include reflective polarizer layers, polarization manipulating means and directional reflectors.

Disclosed is an imaging directional backlight polarization recovery apparatus including an imaging directional backlight with at least a polarization sensitive reflection component with optional polarization transformation and redirection elements. Candidate imaging directional backlights may include a wedge-type directional backlight, an optical inline directional backlight, or an optical valve. The optical valve may include a waveguide, a light source array, and a focusing optic for providing large area directed illumination from localized light sources. The waveguide may include a stepped structure, in which the steps further include extraction features hidden to guided light, propagating in a first forward direction. Returning light propagating in a second backward direction may be refracted, diffracted, or reflected by the features to provide discrete illumination beams exiting from the top surface of the waveguide. Viewing windows may be formed through imaging individual light sources and hence defines the relative positions of system elements and ray paths. The base imaging directional backlight systems provide substantially unpolarized light primarily for the illumination of liquid crystal displays (LCDs) resulting in at least 50% loss in light output when using a conventional sheet polarizer as input to the display. The embodiments herein introduce a polarization sensitive reflecting element to separate desired and undesired polarization states for the purposes of transformation and redirection of the reflected light for usable illumination. Polarization transformation and redirection can be provided by additional components such as retarder films and specular mirror surfaces.

Embodiments herein may provide an autostereoscopic display with large area and thin structure. Further, as will be described, the optical valves of the present disclosure may achieve thin optical components with large back working distances. Such components can be used in directional backlights, to provide directional displays including autostereoscopic displays. Further, embodiments may provide a controlled illuminator for the purposes of an efficient autostereoscopic display.

Embodiments of the present disclosure may be used in a variety of optical systems. The embodiment may include or work with a variety of projectors, projection systems, optical components, displays, microdisplays, computer systems, processors, self-contained projector systems, visual and/or audiovisual systems and electrical and/or optical devices. Aspects of the present disclosure may be used with practically any apparatus related to optical and electrical devices, optical systems, presentation systems or any apparatus that may contain any type of optical system. Accordingly, embodiments of the present disclosure may be employed in optical systems, devices used in visual and/or optical presentations, visual peripherals and so on and in a number of computing environments.

Before proceeding to the disclosed embodiments in detail, it should be understood that the disclosure is not limited in its application or creation to the details of the particular arrangements shown, because the disclosure is capable of other embodiments. Moreover, aspects of the disclosure may be set forth in different combinations and arrangements to define embodiments unique in their own right. Also, the terminology used herein is for the purpose of description and not of limitation.

Directional backlights offer control over the illumination emanating from substantially the entire output surface controlled typically through modulation of independent LED light sources arranged at the input aperture side of an optical waveguide. Controlling the emitted light directional distribution can achieve single person viewing for a security function, where the display can only be seen by a single viewer from a limited range of angles; high electrical efficiency, where illumination is only provided over a small angular directional distribution; alternating left and tight eye viewing for time sequential stereoscopic and autostereoscopic display; and low cost.

The various aspects of the present invention and the various features thereof may be applied together in any combination.

These and other advantages and features of the present disclosure will become apparent to those of ordinary skill in the art upon reading this disclosure in its entirety.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments are illustrated by way of example in the accompanying FIGURES, in which like reference numbers indicate similar parts, and in which:

FIG. **1**A is a schematic diagram illustrating a front view of light propagation in one embodiment of a directional display device, in accordance with the present disclosure;

FIG. **1**B is a schematic diagram illustrating a side view of light propagation in one embodiment of the directional display device of FIG. **1**A, in accordance with the present disclosure;

FIG. **2**A is a schematic diagram illustrating in a top view of light propagation in another embodiment of a directional display device, in accordance with the present disclosure;

FIG. **29** is a schematic diagram illustrating light propagation in a front view of the directional display device of FIG. **2**A, in accordance with the present disclosure;

FIG. **2**C is a schematic diagram illustrating light propagation in a side view of the directional display device of FIG. **2**A, in accordance with the present disclosure;

FIG. **3** is a schematic diagram illustrating in a side view of a directional display device, in accordance with the present disclosure;

FIG. **4**A is schematic diagram illustrating in a front view, generation of a viewing window in a directional display device and including curved light extraction features, in accordance with the present disclosure;

FIG. **4**B is a schematic diagram illustrating in a front view, generation of a first and a second viewing window in a directional display device and including curved light extraction features, in accordance with the present disclosure;

FIG. **5** is a schematic diagram illustrating generation of a first viewing window in a directional display device including linear light extraction features, in accordance with the present disclosure;

FIG. **6**A is a schematic diagram illustrating one embodiment of the generation of a first viewing window in a time multiplexed directional display device, in accordance with the present disclosure;

FIG. **6**B is a schematic diagram illustrating another embodiment of the generation of a second viewing window in a time multiplexed directional display device in a second time slot, in accordance with the present disclosure;

FIG. **6**C is a schematic diagram illustrating another embodiment of the generation of a first and a second viewing window in a time multiplexed directional display device, in accordance with the present disclosure;

FIG. **7** is a schematic diagram illustrating an observer tracking autostereoscopic directional display device, in accordance with the present disclosure;

FIG. **8** is a schematic diagram illustrating a multi-viewer directional display device, in accordance with the present disclosure;

FIG. **9** is a schematic diagram illustrating a privacy directional display device, in accordance with the present disclosure;

FIG. **10** is a schematic diagram illustrating in side view, the structure of a directional display device, in accordance with the present disclosure;

FIG. **11**A is a schematic diagram illustrating a front view of a wedge type directional backlight, in accordance with the present disclosure;

FIG. **11**B is a schematic diagram illustrating a side view of a wedge type directional display device, in accordance with the present disclosure;

FIG. **12** is a schematic diagram illustrating control system for an observer tracking directional backlight apparatus, in accordance with the present disclosure;

FIG. **13**A is a schematic diagram illustrating a polarization recovery approach employed with a wedge type waveguide structure, in accordance with the present disclosure;

FIG. **13**B is a schematic diagram illustrating the elements of a polarization recovery system, in accordance with the present disclosure;

FIG. **14**A is a schematic diagram illustrating a directional backlight employing a polarization recovery approach, in accordance with the present disclosure;

FIG. **14**B is a schematic diagram illustrating a side view of the directional backlight of FIG. **14**A, in accordance with the present disclosure;

FIG. **15**A is a schematic diagram illustrating another system schematic of a directional backlight employing a polarization recovery approach, in accordance with the present disclosure;

FIG. **15**B is a schematic diagram illustrating a system side view illustration of the directional backlight of FIG. **15**A, in accordance with the present disclosure;

FIG. **16**A is a schematic diagram illustrating another directional backlight employing a polarization recovery approach, in accordance with the present disclosure;

FIG. **16**B is a schematic diagram illustrating yet another directional backlight employing a polarization recovery approach, in accordance with the present disclosure;

FIG. **17** is a schematic diagram illustrating yet another directional backlight employing an alternative waveguide structure in which approximately 45° oriented output polarization is provided, in accordance with the present disclosure;

FIG. **18**A is a schematic diagram illustrating an embodiment in which the polarizing reflecting layer is integrated in a single film with the beam deflecting function within a wedge type directional backlight system, in accordance with the present disclosure;

FIG. **18**B is an enlarged cross sectional view of polarization recovery embodiment of FIG. **18**A, in accordance with the present disclosure;

FIG. **18**C is a schematic diagram illustrating another embodiment in which the polarizing reflecting layer is integrated in a single film with the beam deflecting function within a wedge type directional backlight system; in accordance with the present disclosure;

FIG. **18**D is an enlarged cross sectional view of polarization recovery embodiment of FIG. **18**C, in accordance with the present disclosure;

FIG. **19** is a schematic diagram illustrating a side view of a polarisation recovery embodiment, in accordance with the present disclosure;

FIG. **20** is a schematic diagram illustrating a side view of a detail of the polarisation recovery embodiment of FIG. **19**, in accordance with the present disclosure;

FIG. **21** is a schematic diagram illustrating a schematic front view of the polarisation recovery embodiment of FIG. **19**, in accordance with the present disclosure; and

FIG. **22** is a schematic diagram illustrating a side view of a detail of a further polarisation recovery embodiment, in accordance with the present disclosure.

DETAILED DESCRIPTION

Time multiplexed autostereoscopic displays can advantageously improve the spatial resolution of autostereoscopic display by directing light from all of the pixels of a spatial light modulator to a first viewing window in a first time slot, and all of the pixels to a second viewing window in a second time slot. Thus an observer with eyes arranged to receive light in first and second viewing windows will see a full resolution image across the whole of the display over multiple time slots. Time multiplexed displays can advantageously achieve directional illumination by directing an illuminator array through a substantially transparent time multiplexed spatial light modulator using directional optical elements, wherein the directional optical elements substantially form an image of the illuminator array in the window plane.

The uniformity of the viewing windows may be advantageously independent of the arrangement of pixels in the spatial light modulator. Advantageously, such displays can provide observer tracking displays which have low flicker, with low levels of cross talk for a moving observer.

To achieve high uniformity in the window plane, it is desirable to provide an array of illumination elements that have a high spatial uniformity. The illuminator elements of the time sequential illumination system may be provided, for example, by pixels of a spatial light modulator with size approximately 100 micrometers in combination with a lens array. However, such pixels suffer from similar difficulties as for spatially multiplexed displays. Further, such devices may have low efficiency and higher cost, requiring additional display components.

High window plane uniformity can be conveniently achieved with macroscopic illuminators, for example, an array of LEDs in combination with homogenizing and diffusing optical elements that are typically of size 1 mm or greater. However, the increased size of the illuminator elements means that the size of the directional optical elements increases proportionately. For example, a 16 mm wide illuminator imaged to a 65 mm wide viewing window may require a 200 mm back working distance. Thus, the increased thickness of the optical elements can prevent useful application, for example, to mobile displays, or large area displays.

Addressing the aforementioned shortcomings, optical valves as described in commonly-owned U.S. patent application Ser. No. 13/300,293 advantageously can be arranged in combination with fast switching transmissive spatial light modulators to achieve time multiplexed autostereoscopic illumination in a thin package while providing high resolution images with flicker free observer tracking and low levels of cross talk. Described is a one dimensional array of viewing positions, or windows, that can display different images in a first, typically horizontal, direction, but contain the same images when moving in a second, typically vertical, direction.

Conventional non-imaging display backlights commonly employ optical waveguides and have edge illumination from light sources such as LEDs. However, it should be appreciated that there are many fundamental differences in the function, design, structure, and operation between such conventional non-imaging display backlights and the imaging directional backlights discussed in the present disclosure.

Generally, for example, in accordance with the present disclosure, imaging directional backlights are arranged to direct the illumination from multiple light sources through a display panel to respective multiple viewing windows in at least one axis. Each viewing window is substantially formed as an image in at least one axis of a light source by the imaging system of the imaging directional backlight. An imaging system may be formed between multiple light sources and the respective window images. In this manner, the light from each of the multiple light sources is substantially not visible for an observer's eye outside of the respective viewing window.

In contradistinction, conventional non-imaging backlights or light guiding plates (LGPs) are used for illumination of 2D displays. See, e.g., Kälil Käläntär et al., *Backlight Unit With Double Surface Light Emission*, J. Soc. Inf. Display, Vol. 12, Issue 4, pp. 379-387 (December 2004). Non-imaging backlights are typically arranged to direct the illumination from multiple light sources through a display panel into a substantially common viewing zone for each of the multiple light sources to achieve wide viewing angle and high display uniformity. Thus non-imaging backlights do not form viewing windows. In this manner, the light from each of the multiple light sources may be visible for an observer's eye at substantially all positions across the viewing zone. Such conventional non-imaging backlights may have some directionality, for example, to increase screen gain compared to Lambertian illumination, which may be provided by brightness enhancement films such as BEF™ from 3M. However, such directionality may be substantially the same for each of the respective light sources. Thus, for these reasons and others that should be apparent to persons of ordinary skill, conventional non-imaging backlights are different to imaging directional backlights. Edge lit non-imaging backlight illumination structures may be used in liquid crystal display systems such as those seen in 2D Laptops, Monitors and TVs. Light propagates from the edge of a lossy waveguide which may include sparse features; typically local indentations in the surface of the guide which cause light to be lost regardless of the propagation direction of the light.

As used herein, an optical valve is an optical structure that may be a type of light guiding structure or device referred to as, for example, a light valve, an optical valve directional backlight, and a valve directional backlight ("v-DBL"). In the present disclosure, optical valve is different to a spatial light modulator (even though spatial light modulators may be sometimes generally referred to as a "light valve" in the art). One example of an imaging directional backlight is an optical valve that may employ a folded optical system. Light may propagate substantially without loss in one direction through the optical valve, may be incident on an imaging reflector, and may counter-propagate such that the light may be extracted by reflection off tilted light extraction features, and directed to viewing windows as described in U.S. patent application Ser. No. 13/300,293, which is herein incorporated by reference in its entirety.

As used herein, examples of an imaging directional backlight include a stepped waveguide imaging directional backlight, a folded imaging directional backlight, a wedge type directional backlight, or an optical valve.

Additionally, as used herein, a stepped waveguide imaging directional backlight may be an optical valve. A stepped waveguide is a waveguide for an imaging directional backlight including a waveguide for guiding light, further including a first light guiding surface; and a second light guiding surface, opposite the first light guiding surface, further including a plurality of light guiding features interspersed with a plurality of extraction features arranged as steps.

Moreover, as used, a folded imaging directional backlight may be at least one of a wedge type directional backlight, or an optical valve.

In operation, light may propagate within an exemplary optical valve in a first direction from an input side to a reflective side and may be transmitted substantially without loss. Light may be reflected at the reflective side and propagates in a second direction substantially opposite the first direction. As the light propagates in the second direction, the light may be incident on light extraction features, which are operable to redirect the light outside the optical valve. Stated differently, the optical valve generally allows light to propagate in the first direction and may allow light to be extracted while propagating in the second direction.

The optical valve may achieve time sequential directional illumination of large display areas. Additionally, optical elements may be employed that are thinner than the back working distance of the optical elements to direct light from macroscopic illuminators to a window plane. Such displays may use an array of light extraction features arranged to extract light counter propagating in a substantially parallel waveguide.

Thin imaging directional backlight implementations for use with LCDs have been proposed and demonstrated by 3M, for example U.S. Pat. No. 7,528,893; by Microsoft, for example U.S. Pat. No. 7,970,246 which may be referred to herein as a "wedge type directional backlight;" by RealD, for example U.S. patent application Ser. No. 13/300,293 which may be referred to herein as an "optical valve" or "optical valve directional backlight," all of which are herein incorporated by reference in their entirety.

The present disclosure provides stepped waveguide imaging directional backlights in which light may reflect back and forth between the internal faces of, for example, a stepped waveguide which may include a first side and a first set of features. As the light travels along the length of the stepped waveguide, the light may not substantially change angle of incidence with respect to the first side and first set of surfaces and so may not reach the critical angle of the medium at these internal faces. Light extraction may be advantageously achieved by a second set of surfaces (the step "risers") that are inclined to the first set of surfaces (the step "treads"). Note that the second set of surfaces may not be part of the light guiding operation of the stepped waveguide, but may be arranged to provide light extraction from the structure. By contrast, a wedge type imaging directional backlight may allow light to guide within a wedge profiled waveguide having continuous internal surfaces. The optical valve is thus not a wedge type imaging directional backlight.

FIG. **1**A is a schematic diagram illustrating a front view of light propagation in one embodiment of a directional display device, and FIG. **1**B is a schematic diagram illustrating a side view of light propagation in the directional display device of FIG. **1**A.

FIG. **1**A illustrates a front view in the xy plane of a directional backlight of a directional display device, and includes an illuminator array **15** which may be used to illuminate a stepped waveguide **1**. Illuminator array **15** includes illuminator elements **15***a* through illuminator element **15***n* (where n is an integer greater than one). In one example, the stepped waveguide **1** of FIG. **1**A may be a stepped, display sized waveguide **1**. Illumination elements **15***a* through **15***n* are light sources that may be light emitting diodes (LEDs). Although LEDs are discussed herein as illuminator elements **15***a*-**15***n*, other light sources may be used such as, but not limited to, diode sources, semiconductor sources, laser sources, local field emission sources, organic emitter arrays, and so forth. Additionally, FIG. **1**B illustrates a side view in the xz plane, and includes illuminator array **15**, SLM (spatial light modulator) **48**, extraction features **12**, guiding features **10**, and stepped waveguide **1**, arranged as shown. The side view provided in FIG. **1**B is an alternative view of the front view shown in FIG. **1**A. Accordingly, the illuminator array **15** of FIGS. **1**A and **1**B corresponds to one another and the stepped waveguide **1** of FIGS. **1**A and **1**B may correspond to one another.

Further, in FIG. **1**B, the stepped waveguide **1** may have an input end **2** that is thin and a reflective end **4** that is thick. Thus the waveguide **1** extends between the input end **2** that receives input light and the reflective end **4** that reflects the input light back through the waveguide **1**. The length of the input end **2** in a lateral direction across the waveguide is greater than the height of the input end **2**. The illuminator elements **15***a*-**15***n* are disposed at different input positions in a lateral direction across the input end **2**.

The waveguide **1** has first and second, opposed guide surfaces extending between the input end **2** and the reflective end **4** for guiding light forwards and back along the waveguide **1** by total internal reflection. The first guide surface is planar. The second guide surface has a plurality of light extraction features **12** facing the reflective end **4** and inclined to reflect at least some of the light guided back through the waveguide **1** from the reflective end in directions that break the total internal reflection at the first guide surface and allow output through the first guide surface, for example, upwards in FIG. **1**B, that is supplied to the SLM **48**.

In this example, the light extraction features **12** are reflective facets, although other reflective features could be used. The light extraction features **12** do not guide light through the waveguide, whereas the intermediate regions of the second guide surface intermediate the light extraction features **12** guide light without extracting it. Those regions of the second guide surface are planar and may extend parallel to the first guide surface, or at a relatively low inclination. The light extraction features **12** extend laterally to those regions so that the second guide surface has a stepped shape including of the light extraction features **12** and intermediate regions. The light extraction features **12** are oriented to reflect light from the light sources, after reflection from the reflective end **4**, through the first guide surface.

The light extraction features **12** are arranged to direct input light from different input positions in the lateral direction across the input end in different directions relative to the first guide surface that are dependent on the input position. As the illumination elements **15***a*-**15***n* are arranged at different input positions, the light from respective illumination elements **15***a*-**15***n* is reflected in those different directions. In this manner, each of the illumination elements **15***a*-**15***n* directs light into a respective optical window in output directions distributed in the lateral direction in dependence on the input positions. The lateral direction across the input end **2** in which the input positions are distributed corresponds with regard to the output light to a lateral direction to the normal to the first guide surface. The lateral directions as defined at the input end **2** and with regard to the output light remain parallel in this embodiment where the deflections at the reflective end **4** and the first guide surface are generally orthogonal to the lateral direction. Under the control of a control system, the illuminator elements **15***a*-**15***n* may be selectively operated to direct light into a selectable optical window. The optical windows may be used individually or in groups as viewing windows.

The SLM **48** extends across the waveguide is transmissive and modulates the light passing therethrough. Although the SLM **48** may be a liquid crystal display (LCD) but this is merely by way of example, and other spatial light modulators or displays may be used including LCOS, DLP devices, and so forth, as this illuminator may work in reflection. In this example, the SLM **48** is disposed across the first guide surface of the waveguide and modulates the light output through the first guide surface after reflection from the light extraction features **12**.

The operation of a directional display device that may provide a one dimensional array of viewing windows is illustrated in front view in FIG. **1**A, with its side profile shown in FIG. **1**B. In operation, in FIGS. **1**A and **1**B, light may be emitted from an illuminator array **15**, such as an array of illuminator elements **15***a* through **15***n*, located at different positions, y, along the surface of thin end side **2**, x=0, of the stepped waveguide **1**. The light may propagate along +x in a first direction, within the stepped waveguide **1**, while at the same time, the light may fan out in the xy plane and upon reaching the far curved end side **4**, may substantially or entirely fill the curved end side **4**. While propagating, the light may spread out to a set of angles in the xz plane up to, but not exceeding the critical angle of the guide material. The extraction features **12** that link the guiding features **10** of the bottom side of the stepped waveguide **1** may have a tilt angle greater than the critical angle and hence may be missed by substantially all light propagating along +x in the first direction, ensuring the substantially lossless forward propagation.

Continuing the discussion of FIGS. **1**A and **1**B, the curved end side **4** of the stepped waveguide **1** may be made reflective, typically by being coated with a reflective material such as, for example, silver, although other reflective techniques may be employed. Light may therefore be redirected in a second direction, back down the guide in the direction of −x and may be substantially collimated in the xy or display plane. The angular spread may be substantially preserved in the xz plane about the principal propagation direction, which may allow light to hit the riser edges and reflect out of the guide. In an embodiment with approximately 45 degree tilted extraction features **12**, light may be effectively directed approximately normal to the xy display plane with the xz angular spread substantially maintained relative to the propagation direction. This angular spread may be increased when light exits the stepped waveguide **1** through refraction, but may be decreased somewhat dependent on the reflective properties of the extraction features **12**.

In some embodiments with uncoated extraction features **12**, reflection may be reduced when total internal reflection (TIR) fails, squeezing the xz angular profile and shifting off normal. However, in other embodiments having silver coated or metallized extraction features, the increased angular spread and central normal direction may be preserved. Continuing the description of the embodiment with silver coated extraction features, in the xz plane, light may exit the stepped waveguide **1** approximately collimated and may be directed off normal in proportion to the y-position of the respective illuminator element **15***a*-**15***n* in illuminator array **15** from the input edge center. Having independent illuminator elements **15***a*-**15***n* along the input edge **2** then enables light to exit from the entire first light directing side **6** and propagate at different external angles, as illustrated in FIG. **1**A.

Illuminating a spatial light modulator (SLM) **48** such as a fast liquid crystal display (LCD) panel with such a device may achieve autostereoscopic 3D as shown in top view or yz-plane viewed from the illuminator array **15** end in FIG. **2**A, front view in FIG. **2**B and side view in FIG. **2**C. FIG. **2**A is a schematic diagram illustrating in a top view, propagation of light in a directional display device, FIG. **2**B is a schematic diagram illustrating in a front view, propagation of light in a directional display device, and FIG. **2**C is a schematic diagram illustrating in side view propagation of light in a directional display device. As illustrated in FIGS. **2**A, **2**B, and **2**C, a stepped waveguide **1** may be located behind a fast (e.g., greater than 100 Hz) LCD panel SLM **48** that displays sequential right and left eye images. In synchronization, specific illuminator elements **15***a* through **15***n* of illuminator array **15** (where n is an integer greater than one) may be selectively turned on and off, providing illuminating light that enters right and left eyes substantially independently by virtue of the system's directionality. In the simplest case, sets of illuminator elements of illuminator array **15** are turned on together, providing a one dimensional viewing window **26** or an optical pupil with limited width in the horizontal direction, but extended in the vertical direction, in which both eyes horizontally separated may view a left eye image, and another viewing window **44** in which a right eye image may primarily be viewed by both eyes, and a central position in which both the eyes may view different images. In this way, 3D may be viewed when the head of a viewer is approximately centrally aligned. Movement to the side away from the central position may result in the scene collapsing onto a 2D image.

The reflective end **4** may have positive optical power in the lateral direction across the waveguide. In embodiments in which typically the reflective end **4** has positive optical power, the optical axis may be defined with reference to the shape of the reflective end **4**, for example being a line that passes through the centre of curvature of the reflective end **4** and coincides with the axis of reflective symmetry of the end **4** about the x-axis. In the case that the reflecting surface **4** is flat, the optical axis may be similarly defined with respect to other components having optical power, for example the light extraction features **12** if they are curved, or the Fresnel lens **62** described below. The optical axis **238** is typically coincident with the mechanical axis of the waveguide **1**. The cylindrical reflecting surface at end **4** may typically be a spherical profile to optimize performance for on-axis and off-axis viewing positions. Other profiles may be used.

FIG. **3** is a schematic diagram illustrating in side view a directional display device. Further, FIG. **3** illustrates additional detail of a side view of the operation of a stepped waveguide **1**, which may be a transparent material. The stepped waveguide **1** may include an illuminator input side **2**, a reflective side **4**, a first light directing side **6** which may be substantially planar, and a second light directing side **8** which includes guiding features **10** and light extraction features **12**. In operation, light rays **16** from an illuminator element **15***c* of an illuminator array **15** (not shown in FIG. **3**), that may be an addressable array of LEDs for example, may be guided in the stepped waveguide **1** by means of total internal reflection by the first light directing side **6** and total internal reflection by the guiding feature **10**, to the reflective side **4**, which may be a mirrored surface. Although reflective side **4** may be a mirrored surface and may reflect light, it may in some embodiments also be possible for light to pass through reflective side **4**.

Continuing the discussion of FIG. **3**, light ray **18** reflected by the reflective side **4** may be further guided in the stepped waveguide **1** by total internal reflection at the reflective side **4** and may be reflected by extraction features **12**. Light rays **18** that are incident on extraction features **12** may be substantially deflected away from guiding modes of the stepped waveguide **1** and may be directed, as shown by ray **20**, through the side **6** to an optical pupil that may form a viewing window **26** of an autostereoscopic display. The width of the viewing window **26** may be determined by at least the size of the illuminator, output design distance and optical power in the side **4** and extraction features **12**. The height of the viewing window may be primarily determined by the reflection cone angle of the extraction features **12** and the illumination cone angle input at the input side **2**. Thus each viewing window **26** represents a range of separate output directions with respect to the surface normal direction of the spatial light modulator **48** that intersect with a plane at the nominal viewing distance.

FIG. **4**A is a schematic diagram illustrating in front view a directional display device which may be illuminated by a first illuminator element and including curved light extraction features. Further, FIG. **4**A shows in front view further guiding of light rays from illuminator element **15***c* of illuminator array **15**, in the stepped waveguide **1** having an optical axis **28**. In FIG. **4**A, the directional backlight may include the stepped waveguide **1** and the light source illuminator array **15**. Each of the output rays are directed from the input side **2** towards the same viewing window **26** from the respective illuminator **15***c*. The light rays of FIG. **4**A may exit the reflective side **4** of the stepped waveguide **1**. As shown in FIG. **4**A, ray **16** may be directed from the illuminator element **15***c* towards the reflective side **4**. Ray **18** may then reflect from a light extraction feature **12** and exit the reflective side **4** towards the viewing window **26**. Thus light ray **30** may intersect the ray **20** in the viewing window **26**, or may have a different height in the viewing window as shown by ray **32**. Additionally, in various embodiments, sides **22**, **24** of the waveguide **1** may be transparent, mirrored, or blackened surfaces. Continuing the discussion of FIG. **4**A, light extraction features **12** may be elongate, and the orientation of light extraction features **12** in a first region **34** of the light directing side **8** (light directing side **8** shown in FIG. **3**, but not shown in FIG. **4**A) may be different to the orientation of light extraction features **12** in a second region **36** of the light directing side **8**. Similar to other embodiments discussed herein, for example as illustrated in FIG. **3**, the light extraction features of FIG. **4**A may alternate with the guiding features **10**. As illustrated in FIG. **4**A, the stepped waveguide **1** may include a reflective surface on reflective side **4**. In one embodiment, the reflective end of the stepped waveguide **1** may have positive optical power in a lateral direction across the stepped waveguide **1**.

In another embodiment, the light extraction features **12** of each directional backlight may have positive optical power in a lateral direction across the waveguide.

In another embodiment, each directional backlight may include light extraction features **12** which may be facets of the second guide surface. The second guide surface may have regions alternating with the facets that may be arranged to direct light through the waveguide without substantially extracting it.

FIG. **4**B is a schematic diagram illustrating in front view a directional display device which may illuminated by a second illuminator element. Further, FIG. **4**B shows the light rays **40**, **42** from a second illuminator element **15***h* of the illuminator array **15**. The curvature of the reflective surface on the side **4** and the light extraction features **12** cooperatively produce a second viewing window **44** laterally separated from the viewing window **26** with light rays from the illuminator element **15***h*.

Advantageously, the arrangement illustrated in FIG. **4**B may provide a real image of the illuminator element **15***c* at a viewing window **26** in which the real image may be formed by cooperation of optical power in reflective side **4** and optical power which may arise from different orientations of elongate light extraction features **12** between regions **34** and **36**, as shown in FIG. **4**A. The arrangement of FIG. **4**B may achieve improved aberrations of the imaging of illuminator element **15***c* to lateral positions in viewing window **26**. Improved aberrations may achieve an extended viewing freedom for an autostereoscopic display while achieving low cross talk levels.

FIG. **5** is a schematic diagram illustrating in front view an embodiment of a directional display device having substantially linear light extraction features. Further, FIG. **5** shows a similar arrangement of components to FIG. **1** (with corresponding elements being similar), with one of the differences being that the light extraction features **12** are substantially linear and parallel to each other. Advantageously, such an arrangement may provide substantially uniform illumination across a display surface and may be more convenient to manufacture than the curved extraction features of FIG. **4**A and FIG. **4**B. The optical axis **321** of the directional waveguide **1** may be the optical axis direction of the surface at side **4**. The optical power of the side **4** is arranged to be across the optical axis direction, thus rays incident on the side **4** will have an angular deflection that varies according to the lateral offset **319** of the incident ray from the optical axis **321**.

FIG. **6**A is a schematic diagram illustrating one embodiment of the generation of a first viewing window in a time multiplexed imaging directional display device in a first time slot, FIG. **6**B is a schematic diagram illustrating another embodiment of the generation of a second viewing window in a time multiplexed imaging directional backlight apparatus in a second time slot, and FIG. **6**C is a schematic diagram illustrating another embodiment of the generation of a first and a second viewing window in a time multiplexed imaging directional display device. Further, FIG. **6**A shows schematically the generation of viewing window **26** from stepped waveguide **1**. Illuminator element group **31** in illuminator array **15** may provide a light cone **17** directed towards a viewing window **26**. FIG. **6**B shows schematically the generation of viewing window **44**. Illuminator element group **33** in illuminator array **15** may provide a light cone **19** directed towards viewing window **44**. In cooperation with a time multiplexed display, windows **26** and **44** may be provided in sequence as shown in FIG. **6**C. If the image on a spatial light modulator **48** (not shown in FIGS. **6**A, **6**B, **6**C) is adjusted in correspondence with the light direction output, then an autostereoscopic image may be achieved for a suitably placed viewer. Similar operation can be achieved with all the imaging directional backlights described herein. Note that illuminator element groups **31**, **33** each include one or more illumination elements from illumination elements **15***a* to **15***n*, where n is an integer greater than one.

FIG. **7** is a schematic diagram illustrating one embodiment of an observer tracking autostereoscopic display apparatus including a time multiplexed directional display device. As shown in FIG. **7**, selectively turning on and off illuminator elements **15***a* to **15***n* along axis **29** provides for directional control of viewing windows. The head **45** position may be monitored with a camera, motion sensor, motion detector, or any other appropriate optical, mechanical or electrical means, and the appropriate illuminator elements of illuminator array **15** may be turned on and off to provide substantially independent images to each eye irrespective of the head **45** position. The head tracking system (or a second head tracking system) may provide monitoring of more than one head **45**, **47** (head **47** not shown in FIG. **7**) and may supply the same left and right eye images to each viewers' left and right eyes providing 3D to all viewers. Again similar operation can be achieved with all the imaging directional backlights described herein.

FIG. **8** is a schematic diagram illustrating one embodiment of a multi-viewer directional display device as an example including an imaging directional backlight. As shown in FIG. **8**, at least two 2D images may be directed towards a pair of viewers **45**, **47** so that each viewer may watch a different image on the spatial light modulator **48**. The two 2D images of FIG. **8** may be generated in a similar manner as described with respect to FIG. **7** in that the two images would be displayed in sequence and in synchronization with sources whose light is directed toward the two viewers. One image is presented on the spatial light modulator **48** in a first phase, and a second image is presented on the spatial light modulator **48** in a second phase different from the first phase. In correspondence with the first and second phases, the output illumination is adjusted to provide first and second viewing windows **26**, **44** respectively. An observer with both eyes in viewing window **26** will perceive a first image while an observer with both eyes in viewing window **44** will perceive a second image.

FIG. **9** is a schematic diagram illustrating a privacy directional display device which includes an imaging directional backlight. 2D display systems may also utilize directional backlighting for security and efficiency purposes in which light may be primarily directed at the eyes of a first viewer **45** as shown in FIG. **9**. Further, as illustrated in FIG. **9**, although first viewer **45** may be able to view an image on device **50**, light is not directed towards second viewer **47**. Thus second viewer **47** is prevented from viewing an image on device **50**. Each of the embodiments of the present disclosure may advantageously provide autostereoscopic, dual image or privacy display functions.

FIG. **10** is a schematic diagram illustrating in side view the structure of a time multiplexed directional display device as an example including an imaging directional backlight. Further, FIG. **10** shows in side view an autostereoscopic directional display device, which may include the stepped waveguide **1** and a Fresnel lens **62** arranged to provide the viewing window **26** for a substantially collimated output across the stepped waveguide **1** output surface. A vertical diffuser **68** may be arranged to extend the height of the viewing window **26** further. The light may then be imaged through the spatial light modulator **48**. The illuminator array **15** may include light emitting diodes (LEDs) that may, for example, be phosphor converted blue LEDs, or may be separate RGB LEDs. Alternatively, the illuminator elements in illuminator array **15** may include a uniform light source and spatial light modulator arranged to provide separate illumination regions. Alternatively the illuminator elements may include laser light source(s). The laser output may be directed onto a diffuser by means of scanning, for example, using a galvo or MEMS scanner. In one example, laser light may thus be used to provide the appropriate illuminator elements in illuminator array **15** to provide a substantially uniform light source with the appropriate output angle, and further to provide reduction in speckle. Alternatively, the illuminator array **15** may be an array of laser light emitting elements. Additionally in one example, the diffuser may be a wavelength converting phosphor, so that illumination may be at a different wavelength to the visible output light.

FIG. **11**A is a schematic diagram illustrating a front view of another imaging directional backlight, as illustrated, a wedge type directional backlight, and FIG. **11**B is a schematic diagram illustrating a side view of the same wedge type directional display device. A wedge type directional backlight is generally discussed by U.S. Pat. No. 7,660,047 and entitled "Flat Panel Lens," which is herein incorporated by reference in its entirety. The structure may include a wedge type waveguide **1104** with a bottom surface which may be preferentially coated with a reflecting layer **1106** and with an end corrugated surface **1102**, which may also be preferentially coated with a reflecting layer **1106**.

In one embodiment of FIG. **11**B, a directional display device may include a waveguide, such as a wedge type waveguide **1104**, having an input end, first and second opposed guide surfaces for guiding light along the waveguide, and a reflective end facing the input end for reflecting light from the input light back through the waveguide. The directional display device may also include an array of light sources disposed at different input positions across the input end of the waveguide. The waveguide may be arranged to direct input light from the light sources as output light through the first guide surface after reflection from the reflective end into optical windows in output directions relative to the normal to the first guide surface and may be primarily dependent on the input positions. The directional display device may also include a transmissive spatial light modulator, such as display panel **1110**, arranged to receive the output light from the first guide surface and arranged to modulate a first polarization component of the output light having a first polarization. Further, the directional display device may also include a reflective polarizer disposed between the first guide surface of the waveguide and the spatial light modulator and arranged to transmit the first polarization component and to reflect a second polarization component of the output light having a polarization orthogonal to the first polarization as rejected light. The directional display device may also include a rear reflector disposed behind the second guide surface arranged to reflect the rejected light for supply back to the spatial light modulator. The directional display device may further be arranged to convert the polarization of the rejected light supplied back to spatial light modulator into the first polarization.

In one embodiment of a wedge type directional backlight, the first guide surface may be arranged to guide light by total internal reflection and the second guide surface may be substantially planar and inclined at an angle to reflect light in directions that break the total internal reflection for outputting light through the first guide surface. The wedge type directional backlight may be part of a directional display device. The directional display device may also include a deflection element extending across the first guide surface of the waveguide for deflecting light towards the normal to the spatial light modulator.

As shown in FIG. **11**B, light may enter the wedge type waveguide **1104** from local sources **1101** and the light may propagate in a first direction before reflecting off the end surface. Light may exit the wedge type waveguide **1104** while on its return path and may illuminate a display panel **1110**. By way of comparison with an optical valve, a wedge type waveguide provides extraction by a taper that reduces the incidence angle of propagating light so that when the light is incident at the critical angle on an output surface, it may escape. Escaping light at the critical angle in the wedge type waveguide propagates substantially parallel to the surface until deflected by a redirection layer **1108** such as a prism array. Errors or dust on the wedge type waveguide output surface may change the critical angle, creating stray light and uniformity errors. Further, an imaging directional backlight that uses a mirror to fold the beam path in the wedge type directional backlight may employ a faceted mirror that biases the light cone directions in the wedge type waveguide. Such faceted mirrors are generally complex to fabricate and may result in illumination uniformity errors as well as stray light.

The wedge type directional backlight and optical valve further process light beams in different ways. In the wedge type waveguide, light input at an appropriate angle will output at a defined position on a major surface, but light rays will exit at substantially the same angle and substantially parallel to the major surface. By comparison, light input to a stepped waveguide of an optical valve at a certain angle may output from points across the first side, with output angle determined by input angle. Advantageously, the stepped waveguide of the optical valve may not require further light re-direction films to extract light towards an observer and angular non-uniformities of input may not provide non-uniformities across the display surface.

FIG. **12** is a schematic diagram illustrating a directional display apparatus including a display device **100** and a control system. The arrangement and operation of the control system will now be described and may be applied, with changes as necessary, to each of the display devices disclosed herein.

The directional display device **100** includes a directional backlight that includes waveguide **1** and an array of illuminator elements **15** arranged as described above. The control system is arranged to selectively operate the illumination elements **15***a*-**15***n* to direct light into selectable viewing windows.

The waveguide **1** is arranged as described above. The reflective end **4** converges the reflected light. A Fresnel lens **62** may be arranged to cooperate with reflective end **4** to achieve viewing windows **26** at a viewing plane **106** observed by an observer **99**. A transmissive spatial light modulator (SLM) **48** may be arranged to receive the light from the directional backlight. Further a diffuser **68** may be provided to substantially remove Moire beating between the waveguide **1** and pixels of the SLM **48** as well as the Fresnel lens **62**.

The control system may include a sensor system arranged to detect the position of the observer **99** relative to the display device **100**. The sensor system includes a position sensor **70**, such as a camera, and a head position measurement system **72** that may for example include a computer vision image processing system. The control system may further include an illumination controller **74** and an image controller **76** that are both supplied with the detected position of the observer supplied from the head position measurement system **72**.

The illumination controller **74** selectively operates the illuminator elements **15** to direct light to into the viewing windows **26** in cooperation with waveguide **1**. The illumination controller **74** selects the illuminator elements **15** to be operated in dependence on the position of the observer detected by the head position measurement system **72**, so that the viewing windows **26** into which light is directed are in positions corresponding to the left and right eyes of the observer **99**. In this manner, the lateral output directionality of the waveguide **1** corresponds with the observer position.

The image controller **76** controls the SLM **48** to display images. To provide an autostereoscopic display, the image controller **76** and the illumination controller **74** may operate as follows. The image controller **76** controls the SLM **48** to display temporally multiplexed left and right eye images. The illumination controller **74** operate the light sources **15** to direct light into viewing windows in positions corresponding to the left and right eyes of an observer synchronously with the display of left and right eye images. In this manner, an autostereoscopic effect is achieved using a time division multiplexing technique.

As illustrated in FIG. **12**, a directional backlight device may include a stepped waveguide **1** and a light source illuminator array **15**. As illustrated in FIG. **12**, the stepped waveguide **1** includes a light directing side **8**, a reflective side **4**, guiding features **10** and light extraction features **12**.

The above descriptions may apply to each or all of the following apparatuses, modifications and/or additional features, individually, or any combination thereof, which will now be described.

In another embodiment, a directional display device may further include a control system which may be arranged to selectively operate the light sources to direct light into viewing windows corresponding to output directions as previously discussed. This embodiment may also be used in conjunction with any of the directional backlights, directional display devices, directional display apparatuses, and so forth as described herein.

In another embodiment, a directional display apparatus may be an autostereoscopic display apparatus with a control system. The control system may be further arranged to control the directional display device to temporally display multiplexed left and right images and to substantially synchronously direct the displayed images into viewing windows in positions corresponding to at least the left and right eyes of an observer. The control system may include a sensor system which may be arranged to detect the position of an observer across the display device, and also may be arranged to direct the displayed images into viewing windows in positions corresponding to at least the left and right eyes of an observer. The position of the viewing windows may primarily depend on the detected position of the observer.

A polarization recovery approach based on the wedge type directional backlight system of FIGS. **11**A and **11**B is generally discussed in U.S. patent application Ser. No. 13/470,291, which is herein incorporated by reference in its entirety, and is illustrated schematically in FIG. **13**A. FIG. **13**A is a schematic diagram illustrating a polarization recovery approach employed with a wedge type waveguide structure employing a wedge type waveguide **1104** having the arrangement shown and described with reference to FIG. **11**B.

As illustrated in FIG. **13**A, the top surface of the waveguide of a wedge type directional backlight **1104** may be coated with layers **1202** of alternating high and low refractive index materials to provide polarization selective reflection and transmission for those rays **1206** and **1208** that exit. The layers **1202** formed on the first guide surface of the waveguide may form a reflective polarizer by (1) transmitting a first polarization component of the output light from the first guide surface of the waveguide, the first polarization component having a first polarization, and (2) reflecting a second polarization component of the output light as rejected light, the second polarization component having a polarization orthogonal to the first polarization. The narrow range of angles with which light exits this wedge type directional backlight may enable high polarization selectivity with very few coating layers **1202**.

A rear reflecting layer **1212** that functions as a rear reflector is formed on the second guide surface of the waveguide. A retarder film **1214** laminated to the bottom of the waveguide or the second guide surface of the waveguide, may transform the polarization of reflected light to exit following reflection from the reflecting layer **1212**. Unpolarised light ray **1204** is incident on layers **1202** so that ray **1206** is output with a first polarization state and ray **1210** is reflected with a second polarization state orthogonal to the first polarization state, rotated by layer **1212** and output as ray **1208** in the first polarization state.

Continuing the discussion of FIG. **13**A, the retarder film **1214** functions as a phase retarder and may be disposed between the reflective polarizer formed by the layers **1202** and the rear reflector formed by the reflecting layer **212**. The retarder film **1214** may be arranged to convert the polarization of the rejected light into the first polarization when the light exits the wedge type waveguide **1104** for supply back to a spatial light modulator.

FIG. **13**B is a schematic diagram illustrating the elements of a polarization recovery system. Further, FIG. **13**B illustrates a general embodiment of the current disclosure. Imaging directional backlight systems may illuminate with unpolarized light **1302** to provide polarized light for LCDs a polarizing sheet may be used which may absorb at least 50% of the illuminating light. Recovery of this absorbed light may be possible by introducing a reflecting polarizer layer **1306** which functions as a reflective polarizer. The reflecting polarizer layer **1306**, while allowing transmission of light of the desired first polarization component **1310** of a first polarization, may reflect the otherwise lost second polarization component **1314** having a polarization orthogonal to the first polarization, as rejected light. This reflected component then can be altered in polarization most efficiently by a quarter wave retarder **1304** oriented at approximately 45° to the polarization axis of the light that functions as a phase retarder. Redirection of the light through reflection off of mirror **1308** may cause the light to complete a second pass through the quarter wave retarder **1304**, thus substantially completing the polarization transformation and allowing efficient transmission through the reflecting polarizer **1306** as well as making the light **1312** propagate approximately parallel to the light originally transmitted **1310**. In an ideal case little to no light may be lost and the directionality of the combined illumination may be substantially preserved. The polarization conversion and redirection of the reflected component can be achieved by other means such as scattering which may be a property of the underlying backlight illuminator. To achieve some measure of polarization recovery therefore may employ a minimum of a reflecting polarization element.

Distinct from the previous disclosed approach of U.S. patent application Ser. No. 13/470,291, the embodiments of the current disclosure may not rely on reflection of a narrow band, approximately less than 2° of polarized exiting rays and may employ a reflecting polarizer capable of acting on rays at angles with a spread up to and beyond approximately 450 of display viewing angles.

FIG. **14**A is a schematic diagram illustrating a directional backlight employing a polarization recovery approach, and FIG. **14**B is a schematic diagram illustrating a system side view of the directional backlight of FIG. **14**A. Further, FIG. **14**A shows an embodiment of a waveguide structure of the directional backlight with its side view shown in FIG. **14**B, arranged as follows. A stepped waveguide **1406** may have the stepped surface **1502** (first guide surface) coated with a reflecting material such as, but not limited to, Silver or Aluminum to form the rear reflector.

Light rays **1401** propagating within the valve **1406** and reflected from light extraction features of the surface **1502** may be substantially unpolarised. After transmission through a phase retarder such as a quarter wave retarder **1404**, the light remains unpolarised. Light rays **1405** of the desired vertical polarization state **1403** are transmitted through reflective polarizer **1408** and clean-up sheet polarizer **1410** with a vertical polarization transmission orientation for transmission through spatial light modulator **48**. Such rays **1405** may be transmitted through the spatial light modulator with substantially no change to the directionality of the light.

In this embodiment, a reflective polarizer **1408** is arranged in front of the stepped waveguide **1406** and a quarter wave retarder **1404** that functions as a phase retarder may be disposed between the stepped waveguide **1406** and the reflective polarizer **1408**, and thus between the rear reflector formed on the stepped surface **1502** and the reflective polarizer **1408**.

Light rays **1407** of the undesired horizontal linear polarization state **1409** may exit the stepped waveguide **1406** and be reflected from the reflective polarizer **1408** as reflected light. Residual transmission of light in the horizontal polarization state **1409** by the reflective polarizer **1408** may be cleaned up by a sheet polarizer **1410** arranged in front of the reflective polarizer **1408**.

The quarter wave retarder **1404** may be arranged to convert the polarization of the rejected light into the first polarization when supplied back to the spatial light modulator (not shown) that is arranged in front of the sheet polarizer **1410**, as follows. Rejected rays **1407** with a horizontal polarization state may pass back through a quarter wave retarder **1404** with an optical axis oriented at approximately 45°, and thus be converted to circular polarization state **1411**. The respective reflected light may then be transmitted through the transparent optical valve **1406** before being further reflected from the back stepped surface **1502** of the waveguide **1406**. The circular polarization state **1411** of light rays **1407** may be converted on reflection to orthogonal circular polarization state **1413** and become predominantly transformed into the desired vertical polarization state **1417** following a second pass through quarter wave retarder **1404** achieving transmission through reflective polarizer **1408** and clean up polarizer **1410**. The rays **1415** may then combine with those rays **1405** originally transmitted by polariser **1410** to form a substantially uniformly polarized directed beam of effectively substantially twice the original intensity and with the substantially the same directionality. Thus the intensity of viewing windows may be increased with low image cross talk. Small loss of intensity of light rays **1415** may be provided by reduced reflectivity at the side **1502** and other additional losses from Fresnel reflections of the reflected rays **1407**. The quarter wave retarder **1404** may be a single layer retarder with a single optical axis direction. Alternatively retarder layer stacks with increased number of layers and combination of retardances and optical axis directions may be arranged to increase the spectral bandwidth of the retarder as is known. The optical axes of the respective retarders of the stack of retarders may thus be arranged to convert light from linear to circular polarization states as required. The polarization state **1403**, **1417** may be arranged to be aligned with the desired input polarization direction of polarizer **1410** and may be at +/−45° for twisted nematic liquid crystal modes, or may be vertical or horizontal for other known optical modes such as vertical alignment modes.

To maintain the directional fidelity of the original beam, the reflective polarizer **1408** may be approximately parallel with respect to the reflecting surface **1502** and may for example be arranged on the input to the spatial light modulator **48** to provide a substantially planar surface. This can be achieved with a flexible film attached for example by means of lamination onto the clean-up polarizer film adjacent, or directly onto the panel. The clean-up polarizer may typically include an absorption polarizer such as iodine and stretched film. This can be achieved with a flexible film attached with the clean-up polarizer film adjacent, or directly onto the panel.

As discussed herein, a suitable reflective polarizer may be the multi-layer birefringent film for example, a product DBEF supplied by 3M. Another candidate may be a periodic metal wire grid structure on glass with periodicity below the wavelength of visible light such as that supplied by Moxtek. Further, the reflective polarizer as discussed herein may be a similar metal grid structure may be provided on film stock by Asai Kasei.

Efficient polarization transformation may be achieved when the material of the stepped waveguide **1406** exhibits little to no birefringence. The case in which birefringence is oriented along the vertical or horizontal directions as primarily determined by the physical structure of the waveguide, the birefringence may then be compensated by an extra retarder film or more preferably subtracted from a substantially parallel aligned quarter wave retarder. In this last case the film orientations may be preferably oriented with an optical axis at approximately 45 degrees to the orientation shown in FIGS. **14**A and **14**B.

Any additional optical elements such as asymmetric diffusers or Fresnel lenses may be located between the reflective polarizer **1408** and the sheet polarizer **1410**.

In cases in which the reflective polarizer **1408** may cause asymmetric scattering, the orientation of the greatest scattering may be vertical as illustrated by FIG. **14**B. Optical valves in a basic form may act to image in the horizontal plane and may be tolerant to vertical scattering.

FIG. **15**A is a schematic diagram illustrating another system schematic of a directional backlight employing a polarization recovery approach based on a waveguide, and FIG. **15**B is a schematic diagram illustrating a system side view illustration of the directional backlight of FIG. **15**A. Further, FIGS. **15**A and **15**B show an additional embodiment of the current disclosure.

Related to the embodiment of FIGS. **14**A and **14**B, the waveguide structure of this directional backlight may employ a waveguide **1406**, reflective polarizer **1408**, and sheet polarizer **1410** as described above. Replacing a mirrored coating on the stepped surface **1502** (first guide surface) of the waveguide, there may be a separate reflector layer **1402** behind the waveguide **1406** that acts as the rear reflector, and the quarter wave retarder **1404** may be arranged behind the waveguide, in particular between the waveguide and the reflector layer **1402**, as illustrated in FIGS. **15**A and **15**B. In one embodiment, the reflective polarizer may be layers of material of alternating high and low refractive index. Thus light rays **1415**, **1405** may be achieved with substantially the same directionality and polarization state. This embodiment operates in the same manner as the embodiment of FIGS. **14**A and **14**B.

Not having to coat the stepped surface may reduce scattering and cost. Also in placing the retarder layer behind the waveguide, light with linear polarization states may be back reflected through the stepped waveguide providing tolerance to non-uniform, though parallel oriented, birefringence which may be expected in any molded parts. Advantageously, the most common direction of the optical axis of birefringence of the waveguide **1406** may be arranged to be parallel to or orthogonal to the polarization state **1417** to achieve reduced non uniformities of polarization conversion and thus reduced display non uniformities.

FIG. **16**A is a schematic diagram illustrating another directional backlight employing a polarization recovery approach based on an alternative waveguide structure. Further, FIG. **16**A is another embodiment in which an alternate waveguide structure may be employed. Similar to FIG. **14**A, as illustrated, the waveguide structure of FIG. **16**A includes a stepped waveguide **1406**, a quarter wave retarder **1404**, a reflective polarizer **1408**, and a sheet polarizer **1410** arranged and operating in the same manner as the embodiment of FIG. **14**A. In FIG. **16**A, the curved reflector end of the stepped waveguide **1406** may be replaced by a Fresnel reflector equivalent structure, and curved extraction steps may render extraneous any further imaging element on the system such as Fresnel lens **62** shown in FIG. **12**. The stepped surface **1502** of the waveguide **1406** may be directly coated with a reflecting coating to back reflect light for polarization recovery as described for previous embodiments.

FIG. **16**B is a schematic diagram illustrating yet another directional backlight employing polarization recovery approach based on another alternative waveguide structure. Further, FIG. **16**B is a related system embodiment in which an additional polarization rotation film **1602** is disposed between the reflective polarizer **1408** and the spatial light modulator (not shown). The polarization rotation film **1602** acts as a polarization rotator that rotates the first polarization component output from the reflective polarizer **1408** prior to supply to the SLM. This may be used to transform the output linear polarization state **1405**, **1417** to polarization state **1419** from retarder **1602** that may be a half wave retarder that may be a wide band retarder stack with appropriately oriented optical axes. After clean up by polariser **1604** polarisation state **1421** is oriented at approximately 45 degrees to the vertical for more optimum operation with twisted nematic (TN) liquid crystal display (LCD) panels. A substantially parallel **450** aligned clean-up polarizer sheet **1604** may be used in place of the sheet polarizer **1410** to provide highly polarized light at the appropriate orientation for high contrast operation.

As illustrated in FIG. **16**B, a directional display device may include a stepped waveguide **1406**, a quarter wave retarder **1404**, a polarization sensitive layer **1408**, and a sheet polarizer **1410**. The directional display device may further include a polarization rotator disposed between the reflective polarizer and a spatial light modulator. The polarization rotator may be arranged to rotate the first polarization component.

FIG. **17** is a schematic diagram illustrating another directional backlight employing a polarization recovery approach modified as compared to the embodiment of FIG. **16**B to provide an alternative optical valve structure in which approximately 45° oriented output polarization is provided. Further, FIG. **17** is yet another directional backlight employing a polarization recovery approach with film orientations rotated by approximately 45° for direct recovery of TN desired polarized light. Thus polarization states **1423**, **1425** may be arranged at angles other than horizontal and vertical and retarder **1606** arranged to cooperate with the incident polarisation states to achieve polarisation rotation as described above. As described above, the orientation of quarter wave retarder **1606** may be substantially parallel to the physical sides of the optical valve and oriented with respect to any residual birefringence. Choosing a retardation value different to that of a quarter-wave may act to compensate for any residual waveguide birefringence.

FIG. **18**A is a schematic diagram illustrating an embodiment in which the polarizing reflecting layer is integrated in a single film with the beam deflecting function within a wedge type directional backlight with further detail illustrated in FIG. **18**B. Further, FIGS. **18**A and **18**B illustrate an embodiment in which polarization recovery may be employed with a wedge type directional waveguide. A polarization sensitive reflector layer may be coated onto facets **1810** of a redirection film **1108**. The wedge type directional backlight may operate in such a way as to provide an unpolarized, though directed, exiting beam **1802** that may propagate at small angles from the exiting surface. Light within this beam of the undesired polarization state may be reflected downwards off the polarization sensitive reflector layer on facets **1810** and away from the illumination direction. Light **1804** of the desired polarized state, by contrast, may be allowed to be transmitted and redirected upward. The downward propagating beam may pass through the transparent wedge guide material and may be both transformed and redirected back by the quarter wave retarder **1814** and reflecting surface **1106**. This transformed light may pass back through the waveguide **1104** and redirection film **1108** to combine with the initial light beam of the desired polarization.

In one embodiment, a directional display device may include a waveguide in which a first guide surface may be arranged to guide light by total internal reflection and a second guide surface may include a plurality of light extraction features. The light extraction features may be oriented to reflect light guided through the waveguide in directions allowing exit through the first guide surface as the output light. The second guide surface may also include intermediate regions between the light extraction features that may be arranged to direct light through the waveguide without substantially extracting it. Additionally, the light extraction features may be facets of the second guide surface and the second guide surface may have a stepped shape that may include the reflective facets and the intermediate regions. This embodiment and description of a waveguide may be used in conjunction with any of the previously described embodiments that employ a directional display device and/or a waveguide.

FIG. **18**C is a schematic diagram illustrating another polarization recovery embodiment within a wedge type directional backlight with further detail shown in FIG. **18**D. FIG. **18**D is an enlarged cross sectional view of polarization recovery embodiment of FIG. **18**C. Further, FIG. **18**B illustrates a related embodiment to that of FIG. **18**A in which the quarter wave retarder **1814** may be located on the exiting surface of the waveguide rather than between the waveguide and the reflection layer **1812**.

FIG. **19** is a schematic diagram illustrating a side view of a polarization recovery embodiment. The embodiment is generally similar to that shown in FIG. **15**A and described above but modified so that instead of providing the quarter wave retarder **1404**, the rear reflector is arranged to convert the polarization of the rejected light into the first polarization when supplied back to the spatial light modulator.

In this embodiment, a directional display device includes a waveguide **1** and illuminator array **15**, as well as an SLM **48** which receives the output light from the waveguide **1**, being arranged as described above. The display device may further include the following components in series between the waveguide **1** and an SLM **48**, Fresnel lens **62**, optional phase retarder such as a half wave retarder **204**, asymmetric diffuser **68**, reflective polarizer **202**, and clean up polarizer **206** at the input to the spatial light modulator **48**. A prismatic reflective film **200** is disposed behind the second guide surface of the SLM **48** and functions as a rear reflector.

Due to the reflective polarizer **202** that is arranged between the first guide surface of the waveguide **1** and the SLM **48** being arranged to transmit the first polarization component, unpolarized light rays **208** propagating in optical valve **1** are directed as light rays **210** to viewing window **26** in the same manner as the embodiments described above with the first polarization that is transmitted through reflective polarizer **202** and clean up polarizer **206**. Light rays **210** of the second polarization component having a polarization orthogonal to the first polarization are reflected by the reflective polarizer **202** as rejected light and are transmitted through the waveguide **1** to prismatic reflective film **200** whereon they are reflected and directed as light rays **212** back to the SLM **48**. The vertical position of the light ray **212** at window **216** may thus be different to the position of light ray **210**. However, such light rays may include the same optical window directionality in a lateral (y-axis) direction.

The prismatic reflective film **200** converts the polarization of the rejected light into the first polarization as will be described below.

FIG. **20** is a schematic diagram illustrating a side view of a detail of the polarization recovery embodiment of FIG. **19** and FIG. **21** is a schematic diagram illustrating a schematic front view of the polarization recovery embodiment of FIG. **19**. For clarification purposes, Fresnel lens **62** and diffuser **68** are not shown.

Light rays **208** propagating in the waveguide of optical valve **1** include unpolarized light state **230**. Light rays reflected from light extraction features **12** are substantially unpolarized and incident on reflective polarizer **202** as described above. Transmitted rays **210** of the first polarization component are directed through an optional retarder **204** which may be a half wave retarder with appropriately oriented optical axis arranged to direct the first polarization component state **236** on to the transmission axis of clean up polariser **206** of the spatial light modulator **48**.

Spatial light modulator **48** may further include substrates **220**, **224** such as glass substrates, liquid crystal layer **222** and output polariser **226**.

Light rays **212** reflected by reflective polariser **202** as rejected light are transmitted through optical valve **1** and incident on the prismatic reflective film **200** that may include reflective layer **201**, such as an aluminium or silver material. The prismatic reflective film **200** a linear array of pairs of reflective corner facets **203**, **205**. The corner facets **203**, **205** are inclined in opposite senses in a common plane so that the individual light rays **212** undergo a reflection from a pair of the corner facets **212**. That common plane in which the corner facets **203**, **205** are inclined is oriented around the normal to SLM **48** so that the rear reflector converts the polarisation of the rejected light supplied back to spatial light modulator into the first polarisation on reflection from a pair of corner facets. This may be achieved by the common plane extending at 45° to the polarisation of the second polarization component at the prismatic reflective film **200**.

Thus as shown in FIG. **20**, light rays **212** are reflected by both facets **203**, **205** of the prismatic film and may be substantially retroreflected as shown. Light rays **234** are incident at an angle of 45° with respect to the elongate prismatic facets **203**, **205** of the prismatic film **200**. After the double reflection, a polarisation rotation is achieved so that polarisation state **234** is rotated to polarisation state **236** due to the respective phase changes on reflection at each inclined facet. Thus light ray **212** output through the spatial light modulator **48** has the polarisation state **236** that is substantially the same as the polarisation state of rays **212**. Advantageously the present embodiments achieve increased broadband polarisation rotation without the requirement for complex retarder stacks and thus may achieve high brightness output viewing windows with reduced cost.

FIG. **22** is a schematic diagram illustrating a side view of a detail of a further polarisation recovery embodiment. This embodiment is similar to the embodiment of FIG. **20**, however the prismatic film **200** is reversed. Such an arrangement can achieve polarisation rotation over wider illumination angles due to the refraction at the front surface of the film **200**. Further, retarder layers can be incorporated within the film **200** to achieve further control of polarisation rotation.

As may be used herein, the terms "substantially" and "approximately" provide an industry-accepted tolerance for its corresponding term and/or relativity between items. Such an industry-accepted tolerance ranges from zero percent to ten percent and corresponds to, but is not limited to, component values, angles, et cetera. Such relativity between items ranges between approximately zero percent to ten percent.

While various embodiments in accordance with the principles disclosed herein have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of this disclosure should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with any claims and their equivalents issuing from this disclosure. Furthermore, the above advantages and features are provided in described embodiments, but shall not limit the application of such issued claims to processes and structures accomplishing any or all of the above advantages.

Additionally, the section headings herein are provided for consistency with the suggestions under 37 CFR 1.77 or otherwise to provide organizational cues. These headings shall not limit or characterize the embodiment(s) set out in any claims that may issue from this disclosure. Specifically and by way of example, although the headings refer to a "Technical Field," the claims should not be limited by the language chosen under this heading to describe the so-called field. Further, a description of a technology in the "Background" is not to be construed as an admission that certain technology is prior art to any embodiment(s) in this disclosure. Neither is the "Summary" to be considered as a characterization of the embodiment(s) set forth in issued claims. Furthermore, any reference in this disclosure to "invention" in the singular should not be used to argue that there is only a single point of novelty in this disclosure. Multiple embodiments may be set forth according to the limitations of the multiple claims issuing from this disclosure, and such claims accordingly define the embodiment(s), and their equivalents, that are protected thereby. In all instances, the scope of such claims shall be considered on their own merits in light of this disclosure, but should not be constrained by the headings set forth herein.

What is claimed is:

1. A polarized directional illumination apparatus, comprising:

an imaging directional backlight comprising:
- a waveguide for guiding light, further comprising:
  - a first light guiding surface operable to direct light from an illuminator array in a first direction; and
  - a second light guiding surface, operable to allow light to exit the waveguide; and
- a light input surface operable to receive light from the illuminator array;

a polarization sensitive reflector configured to receive light from the waveguide on a first side of the reflector, transmit a first portion of the received light having a first polarization state therethrough towards a second side of the reflector, and reflect a second portion of the received light having a second polarization state back towards the waveguide; and

a retarder configured to receive reflected light from the polarization sensitive reflector and substantially alter the polarization state of the reflected light from the second polarization state to the first polarization state.

2. The polarized directional illumination apparatus of claim **1**, further comprising a retarder film proximate to the second light guiding surface of the waveguide to alter the polarization state of reflected light.

3. The polarized directional illumination apparatus of claim **1**, wherein the waveguide is a wedge type directional backlight.

4. The polarized directional illumination apparatus of claim **3**, wherein the wedge type directional backlight is coated with alternating high refractive index material and low refractive index material.

5. The polarized directional illumination apparatus of claim **3**, wherein the first light guiding surface of the wedge type directional backlight is coated with a reflecting layer.

6. The polarized directional illumination apparatus of claim **1**, wherein the waveguide is an optical valve.

7. The polarized directional illumination apparatus of claim **5**, wherein the optical valve has a stepped surface coated with a reflecting material.

8. The polarized directional illumination apparatus of claim **7**, wherein the optical valve is substantially transparent.

9. The polarized directional illumination apparatus of claim **1**, wherein the polarization sensitive reflector is a multi-layer birefringent film.

10. The polarized directional illumination apparatus of claim **9**, wherein the polarization sensitive reflector is a periodic metal wire grid structure provided on glass.

11. The polarized directional illumination apparatus of claim **9**, wherein the polarization sensitive reflector is a metal grid structure provided on film stock.

12. The polarized directional illumination apparatus of claim **1**, wherein the retarder comprises a quarter-wave plate.

13. An imaging directional backlight comprising:

an input side located at a first end of a waveguide, wherein the input side is operable to receive light from at least an illuminator array;

a reflective side located at a second end of the waveguide;

a first light directing side and a second light directing side located between the input side and the reflective side of the waveguide, wherein the second light directing side is operable to allow light to exit the waveguide;

a polarization sensitive reflector configured to receive light from the waveguide on a first side of the reflector, transmit a first portion of the received light having a first polarization state therethrough towards a second side of the reflector, and reflect a second portion of the received light having a second polarization state back towards the waveguide; and

a retarder configured to receive the reflected light from the polarization sensitive reflector and alter the polarization state of the reflected light from the second polarization state to the first polarization state.

14. The imaging directional backlight of claim **13**, wherein the retarder comprises a quarter-wave plate.

15. An optical valve system that provides polarization recovery, comprising:

a waveguide for guiding light, wherein the waveguide further comprises:

a first light guiding surface; and

a second light guiding surface, opposite the first light guiding surface, further comprising at least one guiding feature and a plurality of extraction features, wherein the plurality of extraction features allow light to pass with substantially low loss when the light is propagating in a first direction and allow light to exit the waveguide upon encountering at least a first extraction feature of the plurality of extraction features;

a spatial light modulator proximate to the waveguide;

a polarization sensitive reflector configured to receive light from the waveguide on a first side of the reflector, transmit a first portion of the received light having a first polarization state therethrough towards a second

side of the reflector, and reflect a second portion of the received light having a second polarization state back towards the waveguide, and

a retarder configured to receive reflected light from the polarization sensitive reflector and alter the polarization state of the reflected light from the second polarization state to the first polarization state.

16. The optical valve system that provides polarization recovery of claim **15**, further comprising a quarter wave retarder plate located between the waveguide and the polarization sensitive reflector.

17. The optical valve system that provides polarization recovery of claim **16**, further comprising a sheet polarizer operable to function as a clean up polarizer and located in a light path after the polarization sensitive reflector.

18. The optical valve system that provides polarization recovery of claim **17**, wherein the optical valve further comprises a stepped surface coated with a reflecting material.

19. The optical valve system that provides polarization recovery of claim **18**, wherein the reflecting material is silver.

20. The optical valve system that provides polarization recovery of claim **18**, wherein the polarization sensitive reflector is approximately parallel to the stepped surface.

21. The optical valve system that provides polarization recovery of claim **15**, wherein the retarder comprises a quarter-wave plate.

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